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CAPSIZE RISK ASSESSMENT USING FREDYN SHIP MOTION PREDICTIONS

K.A. McTaggart

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TECHNICAL MEMORANDUM

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Abstract

This report presents a method for predicting capsize risk of intact ships in a seaway. Ship speed and heading are assumed to be independent variables, and the joint distribution of significant wave height and peak wave period is obtained from a wave scattergram. For a given set of operating and environmental conditions, the time domain program Fredyn is used to determine the occurrence of ship capsize. For irregular seas, the dependence of capsize on wave process realization is modelled by fitting a Gumbel distribution to maximum absolute roll angles obtained from several different wave phase seed numbers. Ten simulations of 30 minute duration can adequately provide the distribution of maximum hourly roll angle for a given seaway and ship operating condition. Sample computations for a Canadian Patrol Frigate suggest that the method gives realistic estimates of annual capsize risk. The current implementation conservatively assumes that ship speed and headings are independent of wave conditions. Future work will examine ship operational profiles to include the influence of capsize avoidance action.

Résumé

Ce rapport présente une méthode qui permet de prédire les risques de chavirement de navires intacts dans une voie maritime. On suppose que la vitesse et le cap sont des variables indépendantes, et que la distribution combinée d'une hauteur de vagues considérable et de la période des vagues les plus fortes a été obtenue au moyen de données disponibles. Pour un ensemble donné de conditions d'exploitation et environnementales, on utilise le programme du domaine temporel Fredyn pour déterminer la limite de chavirement. Dans le cas d'une houle irrégulière, le chavirement du navire causé par le processus des vagues simulées est modélisé par lissage d'une courbe de distribution de Gumbel appliquée aux angles de roulis absolus maxima obtenus au moyen de diverses simulations des vagues. Dix simulations d'une durée de 30 minutes donnent une distribution adéquate de l'angle de roulis horaire maximum dans une condition donnée de voie maritime et de navigation. Des calculs-échantillons faits pour une frégate de patrouille canadienne tendent à confirmer que cette méthode est réaliste dans son estimation du risque annuel de chavirement. La version courante permet de supposer que la vitesse et le cap du navire ne sont pas fonction de l'état des vagues. Des études ultérieures prendront les manoeuvres d'évitement du chavirement en compte pour examiner les profils opérationnels du navire.

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CAPSIZE RISK ASSESSMENT USING FREDYN SHIP MOTION PREDICTIONS

by

Kevin A. McTaggart

EXECUTIVE SUMMARY

Introduction

Probabilistic methods offer the most rational approach for designing safe ships. This report discusses the application of risk analysis to capsize of intact ships. The proposed risk analysis procedure combines input probabilistic distributions of operational and environmental variables with a time domain ship motion program to evaluate capsize risk for a specified duration. The procedure considers the joint distribution of significant wave height and peak wave period.

Principal Results

For a ship of given speed and heading in an irregular seaway with a given significant wave height and peak wave period, the occurrence of capsize depends on how the seaway is modelled. Randomly generated wave phases, which are determined by a wave phase seed number, describe the interaction between individual wave components for a given wave process realization. To model the influence of wave phase seed number on capsize, simulations should be performed with a number of different seed numbers, which produce different maximum roll angles. Extreme value theory suggests that a Gumbel distribution will provide a suitable fit to the resulting maximum roll angles, and this has been confirmed for a majority of cases. For cases with outlier points of high maximum roll angle, the Gumbel distribution should be fitted to the upper range of roll angles, which is of greatest importance for assessing ship capsize risk. A convenient property of the Gumbel distribution is that simulations of shorter duration (e.g. 30 minutes) can be used to determine maximum roll statistics for seaways of longer duration (e.g. one hour). The accuracy of the fitted Gumbel distribution increases with the number of seed numbers and simulation duration. Ten simulations of 30 minute duration provide a reasonable compromise between accuracy and computation time.

Using the fitted Gumbel distributions of maximum roll angle for all combinations of ship speed, heading, wave height, and wave period, the probability of capsize for a nominal duration (e.g. one hour) for all conditions is evaluated. Example computations for a Canadian Patrol Frigate required approximately twenty days of computational time on a personal computer for one ship speed and all relevant combinations of heading, significant wave height, and peak wave period. Results from the sample computations suggest that the method gives realistic predictions of annual capsize risk.

Significance of Results

The developed risk analysis procedure provides a rational basis for assessing intact ship stability. The procedure fully considers the physics of ship capsize while maintaining acceptable

computation times. The fitting of Gumbel distributions to maximum roll angles provides an efficient and accurate method of considering the influence of wave realization for irregular seas.

Future Plans

The most significant planned improvement to the risk analysis will be the inclusion of operator response to wave conditions. Analysis of ship operational profiles will likely give conditional probabilities of ship speed and heading given significant wave height. After this improvement is completed, the selection of appropriate target capsize risk levels will be considered.

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Notation

B	ship beam
C	ship capsize
D	duration
D_s	simulation duration
$E(X)$	expected value of random variable X
$F_X(X)$	cumulative distribution function of variable X
GM_{fluid}	metacentric height, corrected for free surface effects
H_s	significant wave height
$H_{s,max}$	maximum significant wave height for given wave period
$\widehat{H/\lambda}$	nominal wave steepness
k_X	statistical distribution parameter for X
$\overline{KG}$	height of centre of gravity above baseline
L	ship life or length between perpendiculars
N_{cycle}	number of roll cycles
N^{fit}	number of points for fitting Gumbel distribution
N^{fit}_{min}	minimum number of points for fitting Gumbel distribution
N_s	number of wave phase seed numbers
N_X	number of discretized values of variable X
$P(C)$	probability of occurrence of ship capsize
$P(C\|X)$	probability of occurrence of capsize given X
$p_X(X_i)$	probability of occurrence for discrete value X_i
$p_{X\|Y}(X_i\|Y)$	conditional probability of occurrence for discrete value X_i given Y
Q^{fit}_i	exceedence probability for sorted Gumbel fit roll angle ϕ^{fit}_i
$Q_X(X)$	exceedence probability of variable X
$Q_{X\|Y}(X\|Y)$	conditional exceedence probability of variable X given Y
T	ship draft at midships
T_p	peak wave period
T_z	zero-crossing period
t	time
t_s	trim by stern
u_X	statistical distribution parameter for variable X
V_s	ship speed
X	random variable
X_i	discretized value of random variable X
α_X	statistical distribution parameter for variable X
β	incident sea direction (relative to ship speed)
β_X	statistical distribution parameter for variable X
γ	Euler's constant (0.5772...)
Δt	time step
$\Delta\phi^{fit}$	roll angle range for fitting Gumbel distributions
μ_X	mean value of variable X
σ_X	standard deviation of variable X
ϕ	roll angle

ϕ_i^{fit}	sorted Gumbel fit roll angle
ϕ_{limit}	upper limit on valid maximum roll angles
$\phi_{max,D}$	maximum absolute roll angle during seaway of duration D
$\phi_{max,L}$	maximum absolute roll angle during duration L
$\phi_{max,i}$	maximum absolute roll angle for wave phase seed i

1 Introduction

Risk analysis offers the most rational approach for the design of safe ships. Mansour et al. [1] present an overview of the application of risk analysis to ship structural design. Development of risk analysis procedures for ship capsize has been slower than for ship structural design, in part because of the challenges of simulating ship capsize. Dahle and Myrhaug [2, 3] describe recent work in capsize risk analysis for intact ships.

The present report describes a continuation of capsize risk studies in References 4, 5, 6, and 7. A key feature of this ongoing research is that it utilizes a sophisticated time domain program for modelling frigate motions, including capsize. References 8, 9, 10, and 11 describe the Fredyn ship motion program and its application to predicting ship motions in severe conditions.

The current study uses an updated version of the Fredyn program and a more rigourous probabilistic treatment. The present approach considers statistical data for all seaways rather than just data associated with large wave heights. In addition, the present approaches utilizes wave scattergrams, such as those from Bales [12] and BMT Global Wave Statistics [13], to model the correlation between significant wave height and peak wave period in a seaway. Another significant improvement is that the dependence of maximum roll angle on seaway realization is modelled by fitting a Gumbel distribution to maximum roll angle for each combination of ship speed, heading, significant wave height, and peak wave period.

2 Theory

For a ship in a seaway of duration D (e.g. one hour), the exceedence probability of maximum absolute roll angle can be expressed as:

$$Q_{\phi_{max,D}}(\phi_{max,D}) = \sum_{i=1}^{N_{V_s}} \sum_{j=1}^{N_\beta} \sum_{k=1}^{N_{H_s}} \sum_{l=1}^{N_{T_p}} p_{V_s}(V_{s-i})\, p_\beta(\beta_j)\, p_{H_s,T_p}(H_{s-k}, T_{p-l}) \times Q_{\phi_{max,D}|V_s,\beta,H_s,T_p}(\phi_{max,D}|V_{s-i}, \beta_j, H_{s-k}, T_{p-l}) \quad (2.1)$$

where V_s is ship speed, β is the relative wave heading, H_s is significant wave height, and T_p is peak wave period. Each independent variable X in the above equation has been discretized into N_X different values. The last term of Equation (2.1) denotes a conditional probability given a set of operational and seaway conditions.

A key assumption of Equation (2.1) is that ship speed and heading are independent variables. This assumption is conservative because a ship operator will alter speed and heading in extreme conditions to reduce the risk of capsize. Unlike the previous work of Reference 7, Equation (2.1) considers correlation between significant wave height and peak wave period; thus, the equation can fully utilize wave scattergram databases from sources such as Bales [12] and BMT Global Wave Statistics [13].

Wave statistical data are typically based on one hour samples, during which time a wave environment can be assumed to be stationary; thus, Equation (2.1) is suitable for durations of the order of one hour. If roll exceedence probabilities are required for long durations such as the life of a ship L, then the following equation can be used:

$$F_{\phi_{max,L}} = \left[F_{\phi_{max,D}}(\phi_{max,D})\right]^{L/D} \quad (2.2)$$

where $F_X(X)$ is the cumulative distribution function $1 - Q_X(X)$.

One of the most challenging aspects of capsize risk analysis is the determination of the risk of capsize for a given seaway and operational condition. The significant nonlinearities associated with ship capsize require time domain methods for numerical simulation. Fortunately, the time domain code Fredyn gives a good compromise between accuracy and computational effort.

When simulating the motions of a ship in an irregular seaway, the wave system is usually represented by a series of regular wave components with amplitudes determined by wave spectral energy densities for each component frequency. To achieve a realistic random seaway, the phase for each wave component is randomly generated. Reference 7 demonstrated that capsize risk in a seaway can be very sensitive to the initial seed number used to generate the random wave phases; thus, simulations must be performed using several different wave phase seed numbers to determine the risk of capsize in a seaway. Of major concern is the number of different seed numbers required to accurately predict capsize risk in a seaway. Upon initial consideration of capsize as a binary process (i.e. capsize either occurs or doesn't occur in a seaway) it would appear that at least N_s seed numbers would be required to determine a capsize probability of $1/N_s$. For example, at least 100 simulations would be required to determine if the capsize probability in a seaway were of the order of 1/100.

The current study introduces an alternative method for predicting the probability of capsize in a given seaway. References 14 and 15 indicate that the maximum value of a stationary random process during a specified time interval can be modelled using a Gumbel distribution; thus, a Gumbel distribution would likely be appropriate for modelling the maximum roll angle in a one hour seaway. The cumulative distribution function of the Gumbel distribution is as follows:

$$F_X(X) = \exp\{-\exp[-\alpha_X(X - u_X)]\} \tag{2.3}$$

where u_X and α_X are distribution parameters. The mean μ_X and standard deviation σ_X of the Gumbel distribution are related to the distribution parameters as follows:

$$\mu_X = u_X + \frac{\gamma}{\alpha_X} \tag{2.4}$$

$$\sigma_X = \frac{\pi}{\alpha_X \sqrt{6}} \tag{2.5}$$

where γ is Euler's constant (0.5772...).

Two methods are available for determining Gumbel distribution parameters. The method of moments relates the distribution parameters to the computed mean and standard deviation for the variable X. The second method uses a least squares linear fit between the variable X or its transformation (e.g. $\ln X$) and the cumulative distribution function $F_X(X)$ or its transformation (e.g. $\ln F_X(X)$). A significant advantage of the least squares method is that it can be applied to a limited probability range of greatest interest. When simulating ship motions using the program Fredyn, a simulation will terminate when the ship roll angle exceeds 90 degrees; thus, a Gumbel least squares fit provides a suitable approach for handling the limited range of valid maximum roll angles.

The equation for determining a least squares fit of Gumbel parameters is as follows:

$$X = \frac{1}{-\alpha_X} \ln[-\ln(F_X(X))] + u_X \tag{2.6}$$

The regression fit has a slope of $1/\alpha_X$ and an intercept of u_X. When determining the least squares fit parameters from N_s simulations in a given seaway, the simulated maximum roll angles can be ranked in ascending order to assign cumulative distribution values as follows:

$$F(\phi_{max,i}) = \frac{i}{N_s + 1} \tag{2.7}$$

where $\phi_{max,i}$ is the sorted maximum roll angle with rank i in ascending order. Once the Gumbel parameters have been determined using a least squares fit for a given seaway, the associated capsize probability can be easily estimated using Equation (2.3).

If a maximum value from simulation duration D_s has a Gumbel distribution, then the maximum value for another duration D will have the following properties:

$$\sigma_X(D) = \sigma_X(D_s) \tag{2.8}$$

$$\mu_X(D) = \mu_X(D_s) + \frac{\sqrt{6}}{\pi} \ln\left(\frac{D}{D_s}\right) \sigma_X(D_s) \tag{2.9}$$

The above equations imply that a shorter simulation duration D_s can be used for determining Gumbel distribution parameters for a longer duration D.

In Section 5, maximum roll angles from simulations are plotted with fitted Gumbel distributions. Fits from type II and Weibull distributions (see Reference 15) are also given for comparison. The type II distribution is as follows:

$$F_X(X) = \exp\left[-(u_X/x)^{k_X}\right] \tag{2.10}$$

where u_X and k_X are distribution parameters. The mean and standard deviation for the type II distribution are:

$$\mu_X = u_X \, \Gamma\left(1 - \frac{1}{k_X}\right) \tag{2.11}$$

$$\sigma_X = u_X \sqrt{\Gamma\left(1 - \frac{2}{k_X}\right) - \Gamma^2\left(1 - \frac{1}{k_X}\right)} \tag{2.12}$$

where $\Gamma(x)$ is the Gamma function. The 2-parameter Weibull is given by:

$$F_X(X) = 1 - \exp\left[-(u/k_X)^{\beta_X}\right] \tag{2.13}$$

where k_X and β_X are distribution parameters. The mean and standard deviation for the Weibull distribution are:

$$\mu_X = k_X \, \Gamma\left(1 + \frac{1}{\beta_X}\right) \tag{2.14}$$

$$\sigma_X = k_X \sqrt{\Gamma\left(1 + \frac{2}{\beta_X}\right) - \Gamma^2\left(1 + \frac{1}{\beta_X}\right)} \tag{2.15}$$

Parameters for the type II and Weibull distributions can be found using a least square fit procedure similar to that used for the Gumbel distribution.

3 Sources of Wave Statistics

The present risk analysis procedure requires the joint distribution of significant wave height and peak wave period as input. Bales et al. [12, 16] have published wave scattergrams developed using the SOWM wave hindcast model. BMT Global Wave Statistics [13] is another commonly used data source for wave scattergrams.

The present study originally used wave data for Area 15 (western portion of North Atlantic) from BMT Global Wave Statistics; however, the resulting Fredyn simulations often experienced numerical instabilities, and predicted capsize risks appeared to be unrealistically high. It was postulated that these problems were caused by unrealistically high wave steepnesses in the BMT data, which are based primarily on visual observations of wave conditions.

To assess the validity of BMT wave data, it is useful to compare them with data from Bales [12]. Tables 1 and 2 give annual wave scattergrams for the North Atlantic from BMT and Bales respectively. The wave heights in the left-hand columns of each table represent mid-range values. Note that BMT use zero-crossing wave period when presenting wave data while Bales uses peak wave period. When comparing the two different data sources, the following equation based on a Bretschneider spectrum can be used:

$$T_p = 1.408\, T_z \tag{3.1}$$

The introduction of nominal wave steepness $\widetilde{H/\lambda}$ below also facilitates comparison of data from the two data sources:

$$\widetilde{H/\lambda} = \frac{2\,\pi\,H_s}{g\,T_p^2} \tag{3.2}$$

Figure 1 shows maximum observed nominal significant wave height versus peak wave period from the Bales and BMT wave data. For many peak wave periods, the maximum significant wave height from the BMT data is approximately twice as large as from Bales. Among the Bales data, the maximum significant wave height for a wave period of 9.7 s is greater than the other data would suggest. Figure 2 gives maximum nominal steepness versus peak wave period, and is particularly enlightening when compared to other published wave data. McTaggart [7] gives an analysis of storm data for George's Bank from Reference 17, and gives a maximum nominal steepness of 0.041 for 68 storms. De Kat [18] and Faulkner and Williams [19] cite several sources which indicate a maximum possible nominal steepness of 0.05 in deep water. Olagnon and Krogstad [20] give extensive observations for a North Sea location, indicating a maximum possible nominal steepness of approximately 0.06. It appears that the BMT wave data for Area 15 give unrealistically high wave steepnesses. In contrast, the North Atlantic data from Bales give steepnesses which are consistent with other data sources, with the exception of the single observation of $H_s = 8.5$ m and $T_p = 9.7$ s. For the present capsize risk analysis study, the Bales North Atlantic scattergram is used, with the $H_s = 8.5$ m, $T_p = 9.7$ s observation changed to $H_s = 6.5$ m, $T_p = 9.7$ s.

4 Software Implementation

The prediction of ship capsize risk has been implemented as a two step process. The program Pcapref computes maximum roll angles from Fredyn 7.0 [21] for all specified values of ship speed,

Hs (m)	Wave Period Tz (s)									
	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5
0.5	195	5148	22478	31077	18074	5512	1059	147	16	2	
1.5	6	1241	20714	71775	86236	49613	16978	4018	730	110	14
2.5		230	7349	43695	83798	72651	35743	11681	2838	555	93
3.5		45	2203	18702	49097	56350	35688	14653	4377	1034	205
4.5		9	631	6984	23184	32851	25176	12298	4304	1175	267
5.5		2	181	2480	9923	16639	14855	8342	3316	1018	257
6.5		1	54	876	4092	7893	8001	5046	2232	756	209
7.5			17	316	1683	3659	4136	2881	1396	514	154
8.5			5	118	704	1700	2113	1605	842	334	107
9.5			2	46	303	803	1085	890	502	212	72
10.5			1	19	135	388	566	497	299	134	48
11.5				8	62	192	300	281	179	85	32
12.5				3	29	97	162	161	108	54	21
13.5				2	14	51	89	93	66	34	14
14.5				1	15	58	115	134	105	61	28

Table 1: BMT Global Wave Statistics Scattergram for Area 15, Western Portion of North Atlantic

Hs (m)	Wave Period Tp (s)													
	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	541	341	5488	5622	3892	4861	2667	2612	1180	1321	592	213	52	4	0
1.5	0	289	3929	6631	5475	5361	3627	3428	1617	1707	945	569	164	10	0
2.5	0	0	29	2150	5501	5695	3829	2968	1598	1267	780	421	124	3	0
3.5	0	0	0	5	822	4582	3873	3393	1457	1098	623	350	97	6	0
4.5	0	0	0	0	13	613	3115	3381	1293	1008	556	316	75	12	0
5.5	0	0	0	0	0	22	631	3014	1263	993	467	308	48	5	0
6.5	0	0	0	0	0	1	27	1336	1103	934	429	287	40	0	0
7.5	0	0	0	0	0	0	0	229	722	778	347	230	28	0	6
8.5	0	0	0	0	0	1	0	16	218	599	310	200	31	0	7
9.5	0	0	0	0	0	0	0	2	26	187	316	163	20	2	1
10.5	0	0	0	0	0	0	0	0	1	41	202	106	21	1	0
11.5	0	0	0	0	0	0	0	0	0	7	67	95	15	0	1
12.5	0	0	0	0	0	0	0	0	0	0	13.5	57.5	17.5	0	0
13.5	0	0	0	0	0	0	0	0	0	0	13.5	57.5	17.5	0	0
14.5	0	0	0	0	0	0	0	0	0	0	0	13	13	1.5	0.5
15.5	0	0	0	0	0	0	0	0	0	0	0	13	13	1.5	0.5
16.5	0	0	0	0	0	0	0	0	0	0	0	0	2.5	2.5	0
17.5	0	0	0	0	0	0	0	0	0	0	0	0	2.5	2.5	0
18.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5
19.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5

Table 2: Bales Wave Scattergram for North Atlantic

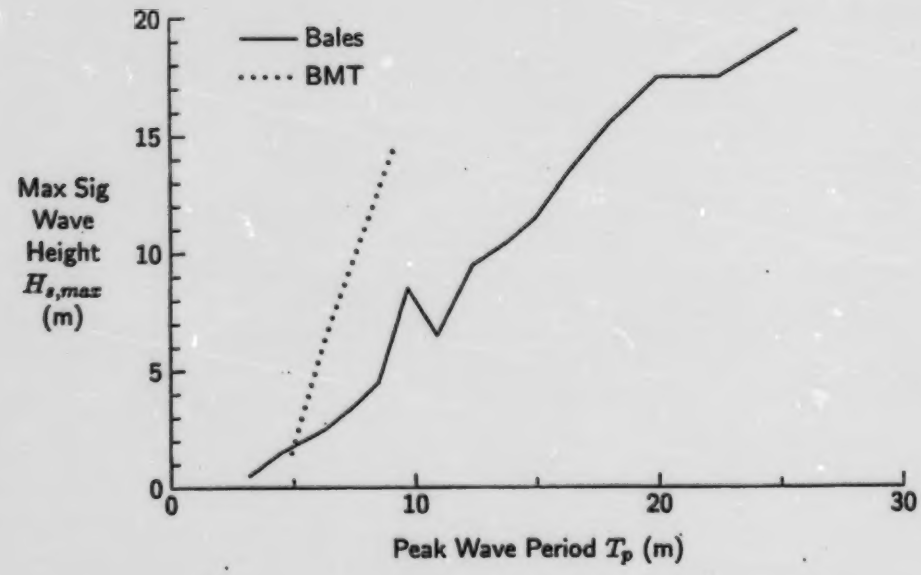

Figure 1: Maximum Significant Wave Height Versus Peak Wave Period

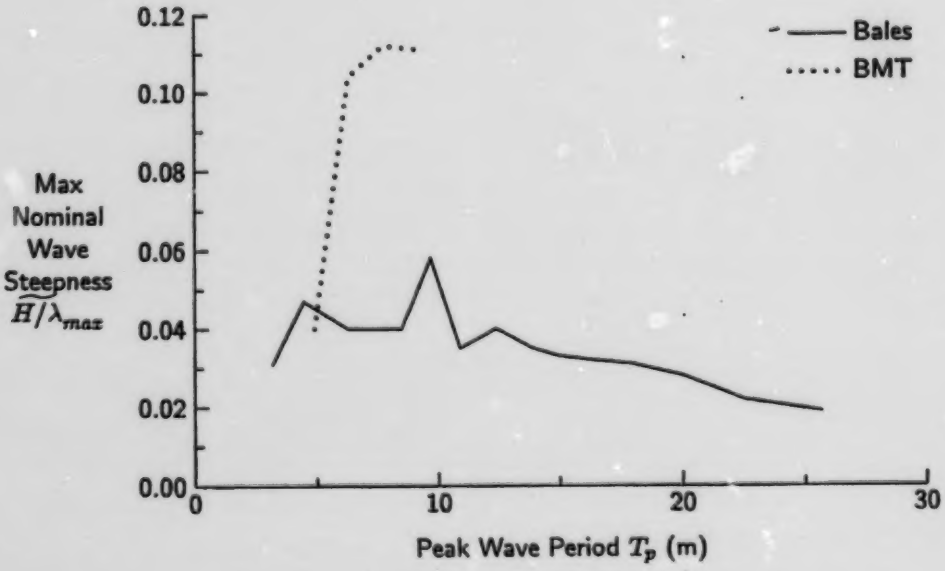

Figure 2: Maximum Nominal Wave Steepness Versus Peak Wave Period

heading, significant wave height, peak wave period, and wave seed numbers. The program Pcapsize2 then combines the maximum roll angles from Pcapref with input statistical data to determine capsize probabilities using Equation (2.1). Appendices A and C describe main input files for the programs Pcapref and Pcapsize2. Appendix E.1 gives the format for wave scatergram files which are read by Pcapsize2.

During development of Pcapref, a main objective was to facilitate easy integration with the program Fredyn provided by MARIN, which is frequently upgraded. The main module of Fredyn was easily converted to a subroutine with no input parameters. Before each call to the Fredyn subroutine, the main program Pcapref writes a new Fredyn input file with wave and ship operational parameters set as required. The user must provide a base Fredyn input file, which Pcapref uses when preparing subsequent Fredyn input files.

Initial runs with Pcapref revealed that the statistical summary produced by Fredyn is incorrect when the Fredyn input variable TSTAT has a non-zero value. This problem was circumvented by having Pcapref compute motion statistics using the time series file produced by Fredyn. Program Pcapref also checks the time series file to ensure that a simulation has been completed.

The program Pcapref can require several days to run, and sometimes terminates prematurely due to numerical problems, power failures, or other problems. To reduce the effects of unexpected interruptions, the program can save simulation results to an ASCII data file and then read these results when the program is restarted.

Under conditions for which roll responses are small, program Pcapref can assume that maximum roll angle is linear with significant wave height. This feature reduces the number of required time domain simulations for a ship. Associated user input includes a base wave height for reference roll calculations and a limit on the acceptable maximum roll angle for linear response.

5 Parametric Simulations of a Ship in Irregular Seas

Initial parametric simulations were conducted to examine the statistical properties of maximum roll angle. Of major concern was the applicability of a Gumbel distribution to maximum roll angle. The Canadian Patrol Frigate was used for the parametric simulations, with properties as given in Table 3. The metacentric height of 1.224 m is based on a dry metacentric height of 1.434 m computed by the Fredyn pre-processor Freinp minus a correction of 0.21 m for free-surface effects. All simulations were done for a calm water ship speed of 10 knots. Unless otherwise specified, 10 different wave phase seed numbers were used for simulations of 10 minute duration. The conditions for the parametric simulations were selected because they were among the most likely to cause ship capsize, as determined in the risk analysis presented in Section 6.

Figures 3 and 4 show the mean and standard deviation of maximum roll angle versus significant wave height for a heading of 60 degrees and peak wave period of 12.4 s. These figures also show predicted values based on RMS roll and linear theory, for which Reference 14 give the following equations for a narrow-banded Gaussian process:

$$E(\phi_{max}) = \sigma_\phi \left[\sqrt{2 \ln N_{cycle}} + \frac{\gamma}{\sqrt{2 \ln N_{cycle}}} \right] \tag{5.1}$$

$$\sigma(\phi_{max}) = \sigma_\phi \frac{\pi}{\sqrt{6}} \frac{1}{\sqrt{2 \ln N_{cycle}}} \tag{5.2}$$

Table 3: Main Particulars for Canadian Patrol Frigate

Length, L	124.5 m
Beam, B	14.7 m
Midships draft, T	4.64 m
Trim by stern, t_s	0.0 m
Displacement, Δ	4077 tonnes
Vertical centre of gravity, $\overline{KG}$	6.44 m
Corrected metacentric height, GM_{fluid}	1.224 m

where σ_ϕ is the RMS roll angle and N_{cycle} is the number of roll cycles. Figure 3 indicates that the maximum roll angle increases approximately linearly with wave height up to a wave height of 8 m. For larger wave heights, maximum roll angle increases sharply with wave height. The maximum roll angles predicted using Equation (5.1) show good agreement with the actual values when the wave height is below 8 m. In Figure 4, the standard deviation of maximum roll angle from simulations is a non-smooth function of significant wave height. The large standard deviations at higher wave heights indicate that maximum roll angle becomes more dependent on the input wave phase seed number. A larger number of simulations would likely give a smoother function for standard deviation versus wave height. Equation (5.2) severely underpredicts the standard deviation of maximum roll at higher wave heights.

Figures 5 and 6 show the expected value and standard deviation of maximum roll angle versus simulation duration for a heading of 60 degrees, peak wave period of 12.4 s, significant wave height of 9.5 m. These figures also give predicted values for one hour duration based on Equations (2.8) and (2.9). As expected, Figure 5 shows that the mean value for maximum roll angle increases with simulation duration. Equation (2.9) tends to overpredict the hourly maximum roll angle, with the degree of overprediction decreasing as simulation duration increases. Although Equation (2.8) indicates that the standard deviation of maximum roll will be independent of simulation duration, Figure 6 suggests that the standard deviation fluctuates as simulation duration increases. For longer simulation durations, the standard deviation appears to converge.

Figures 7 and 8 show the influence of the number of simulations on statistics for maximum roll angle. Both the mean and standard deviation converge as the number of simulations increases. Ten simulations appear to provide a reasonable compromise between accuracy and computational time.

Roll exceedence probabilities and fitted distributions are given for significant wave heights of 9.5 m and 11.5 m in Figures 9 and 10. The Gumbel distribution provides a good fit to the computed maximum roll angles, particularly for large values. The type II maximum distribution also gives a good fit to maximum roll angles. The poorer fit of the Weibull distribution occurs is expected because the Weibull distribution has been derived to model minimum rather than maximum values. In Figure 10, the concentration of data at a roll angle of 90 degrees is caused by the termination of Fredyn when roll angle exceeds 90 degrees.

Figures 11 and 12 show fitted Gumbel distributions for maximum hourly roll angle derived

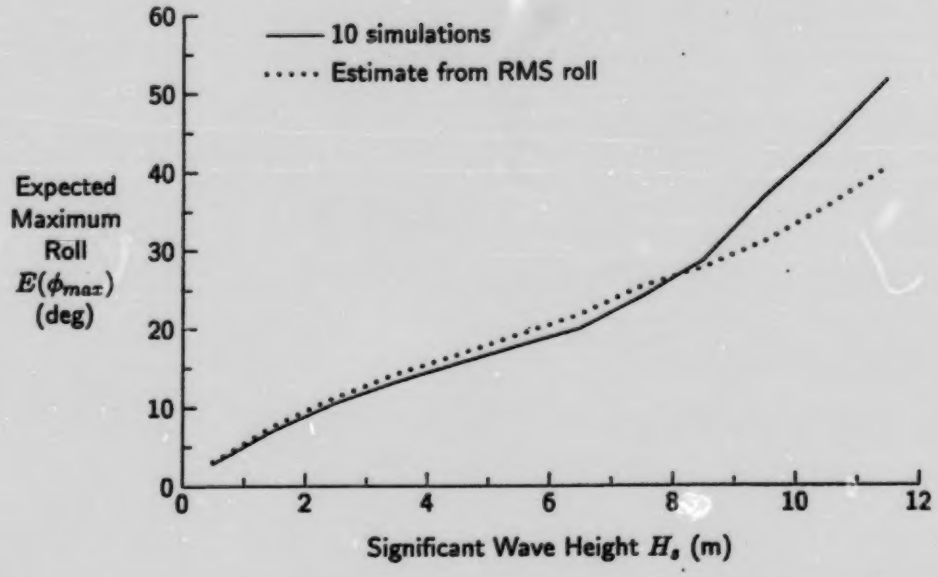

Figure 3: Expected Value of Maximum Roll Versus Significant Wave Height, $\beta = 60$ degrees, $T_p = 12.4$ s

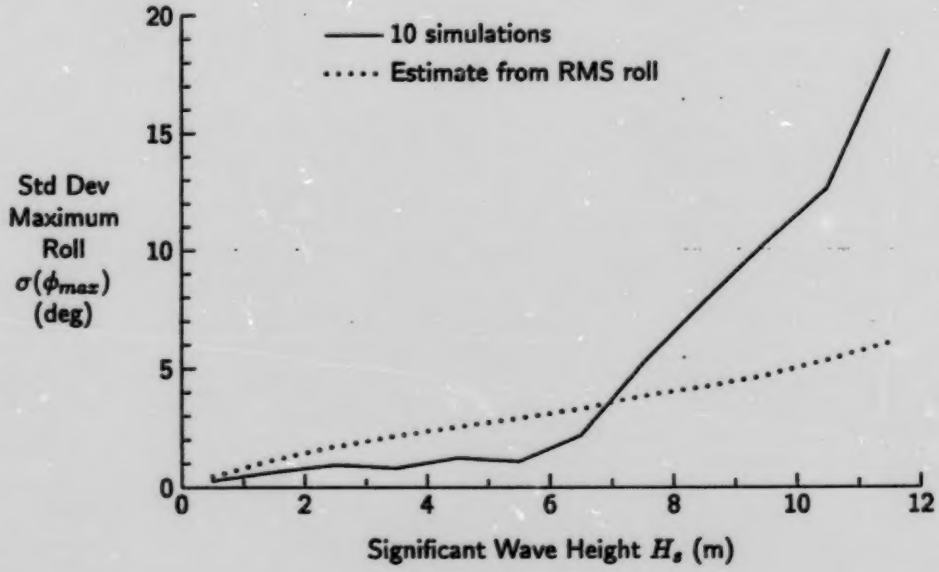

Figure 4: Standard Deviation of Maximum Roll Versus Significant Wave Height, $\beta = 60$ degrees, $T_p = 12.4$ s

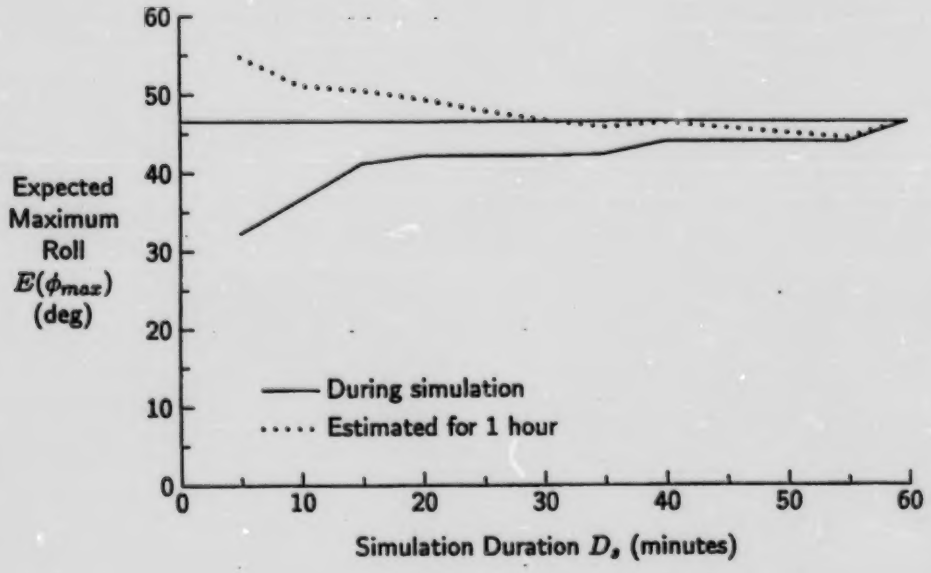

Figure 5: Expected Value of Maximum Roll Versus Simulation Duration, $\beta = 60$ degrees, $T_p = 12.4$ s, $H_s = 9.5$ m

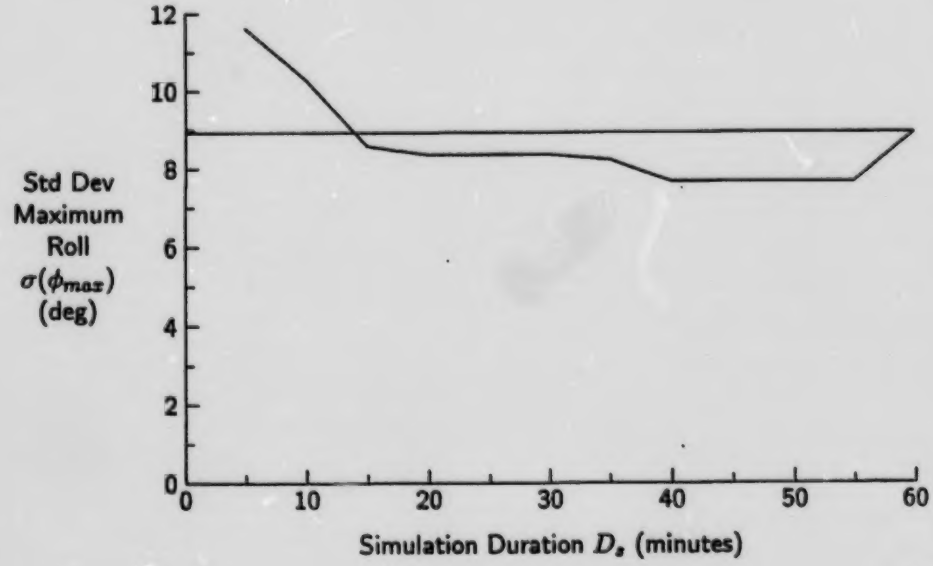

Figure 6: Standard Deviation of Maximum Roll Versus Simulation Duration, $\beta = 60$ degrees, $T_p = 12.4$ s, $H_s = 9.5$ m

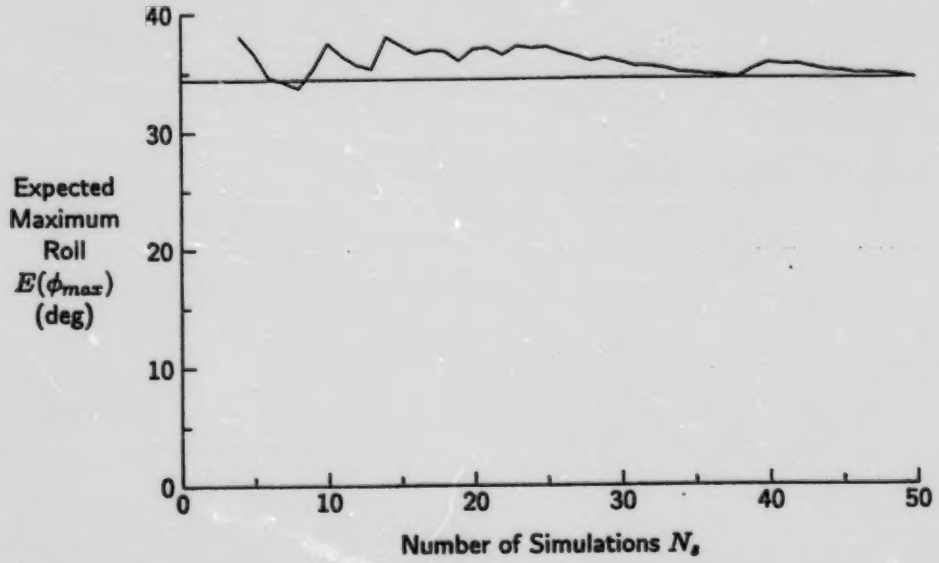

Figure 7: Expected Value of Maximum Roll Versus Number of Simulations, $\beta = 60$ degrees, $T_p = 12.4$ s, $H_s = 9.5$ m

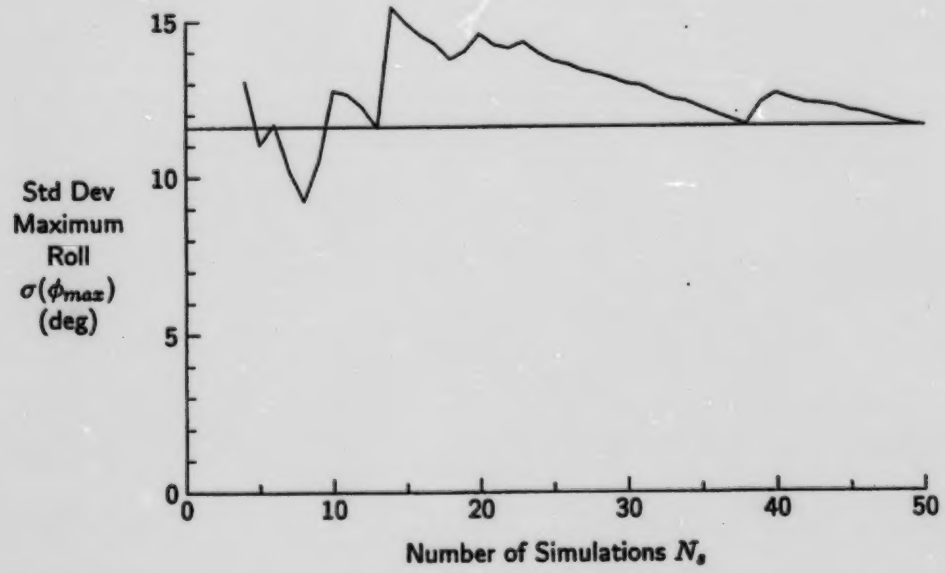

Figure 8: Standard Deviation of Maximum Roll Versus Number of Simulations, $\beta = 60$ degrees, $T_p = 12.4$ s, $H_s = 9.5$ m

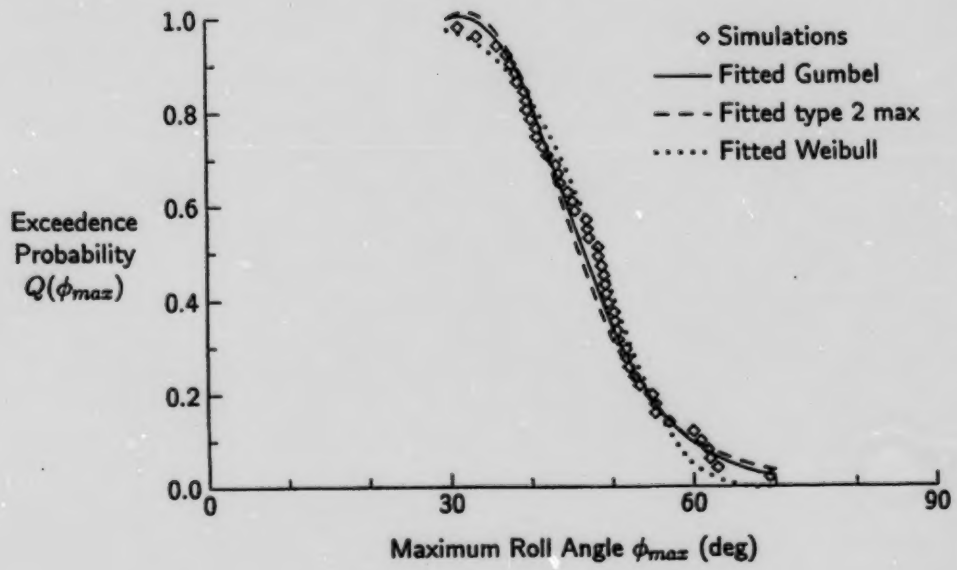

Figure 9: Roll Exceedence Probability Versus Roll Angle for Different Distributions, $\beta = 60$ degrees, $T_p = 12.4$ s, $H_s = 9.5$ m

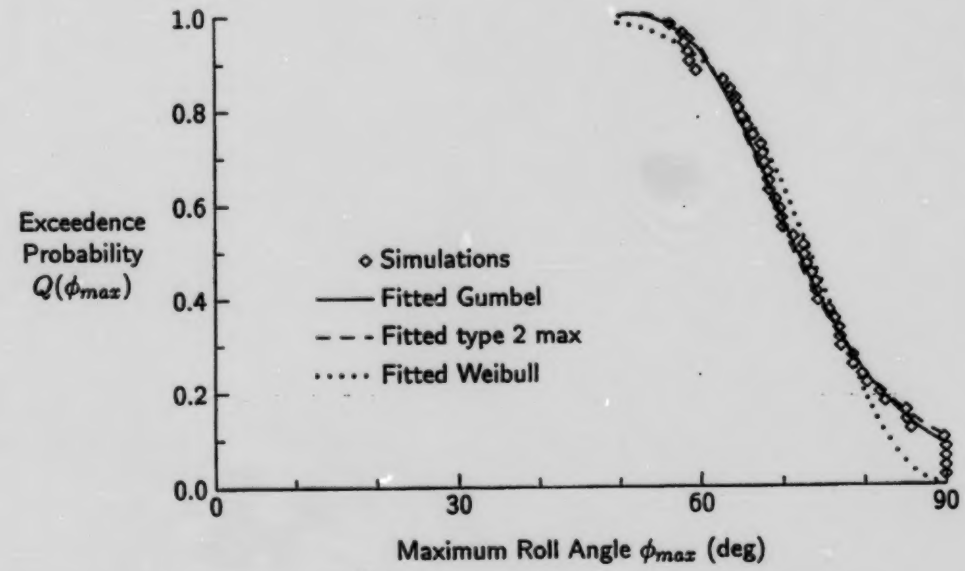

Figure 10: Roll Exceedence Probability Versus Roll Angle for Different Distributions, $\beta = 60$ degrees, $T_p = 12.4$ s, $H_s = 11.5$ m

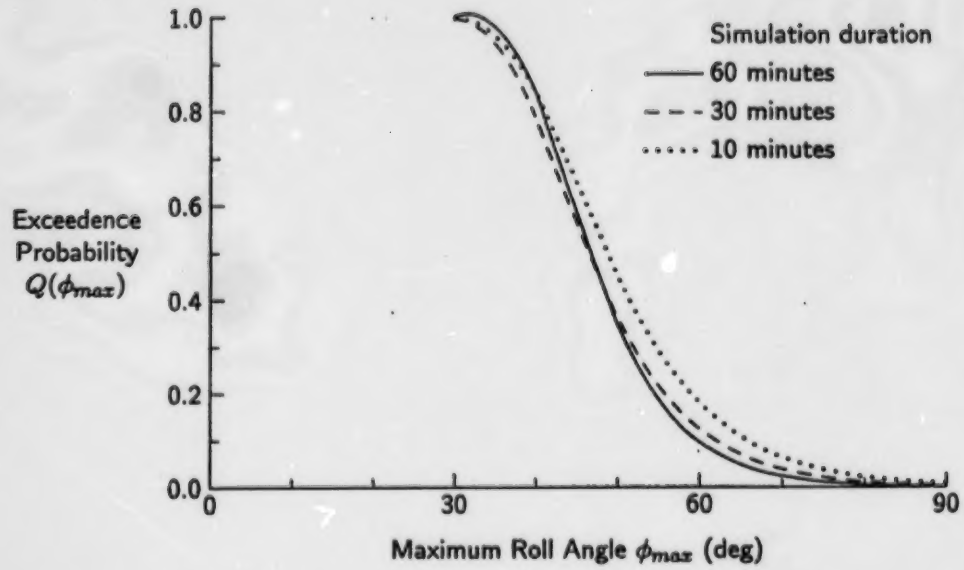

Figure 11: Hourly Roll Exceedence Probability Versus Roll Angle from Different Simulation Durations, 50 Realizations, $\beta = 60$ degrees, $T_p = 12.4$ s, $H_s = 9.5$ m

from simulation durations of 10, 30, and 60 minutes. For large roll angles, the 10 and 30 minute simulations generally lead to overprediction of exceedence probability for hourly maximum roll angles, with the overprediction being smaller for the 30 minute simulations.

Figures 13 and 14 show fitted distributions based on 10 and 50 simulations of one hour duration. Figure 14 indicates that using only 10 simulations can lead to roll exceedence probability being significantly underpredicted.

The results presented thus far are for cases where a Gumbel distribution provides a good fit to maximum roll angles from simulations. When performing the risk analysis in Section 6, it was found that a Gumbel distribution provides a good fit for most but not all conditions. A poor Gumbel fit can be detected by examining the maximum difference between the simulation and Gumbel fit maximum roll angles for simulation exceedence probabilities. For example, a maximum difference of greater than 10 degrees between simulation and Gumbel fit roll angle likely indicates a poor Gumbel fit. Figure 15 gives an example of a poor Gumbel fit.

It was found that poor Gumbel fits typically occur when outlier points occur, which are typically indicated by maximum roll angles from simulations having a range greater than 40 degrees. A practical solution is to fit the Gumbel distribution only to higher roll angles, which are of greatest importance for ship capsize. Control of the Gumbel fit can be determined by the parameters $\Delta\phi^{fit}$ and N_{min}^{fit}, where $\Delta\phi^{fit}$ is the desired range of maximum roll angles and N_{min}^{fit} is the minimum number of maximum roll angles for application of the Gumbel fit. The following process can then be used for determining the maximum roll angles to be used for a Gumbel fit:

1. Sort simulation roll angles in descending order to obtain vector of maximum roll angles

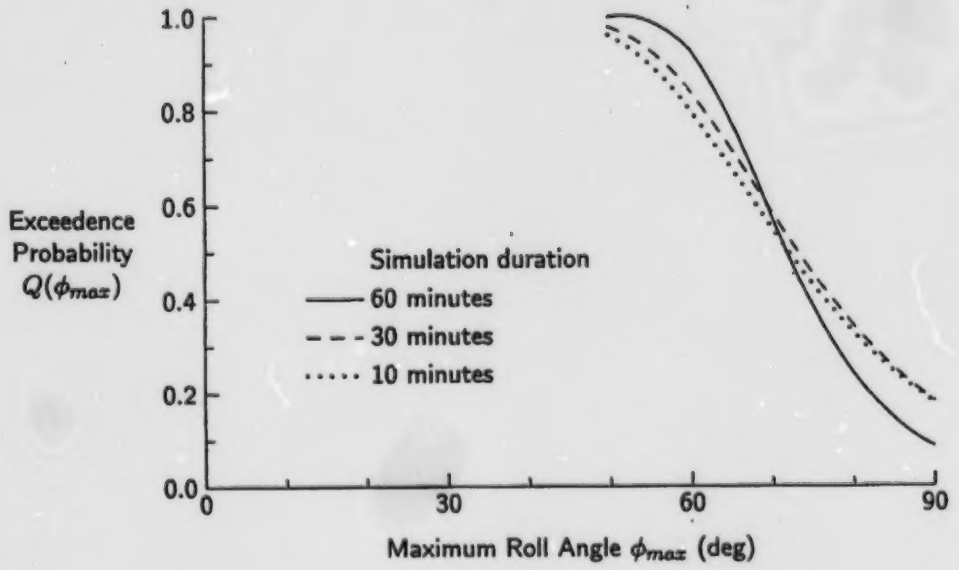

Figure 12: Hourly Roll Exceedence Probability Versus Roll Angle from Different Simulation Durations, 50 Realizations, $\beta = 60$ degrees, $T_p = 12.4$ s, $H_s = 11.5$ m

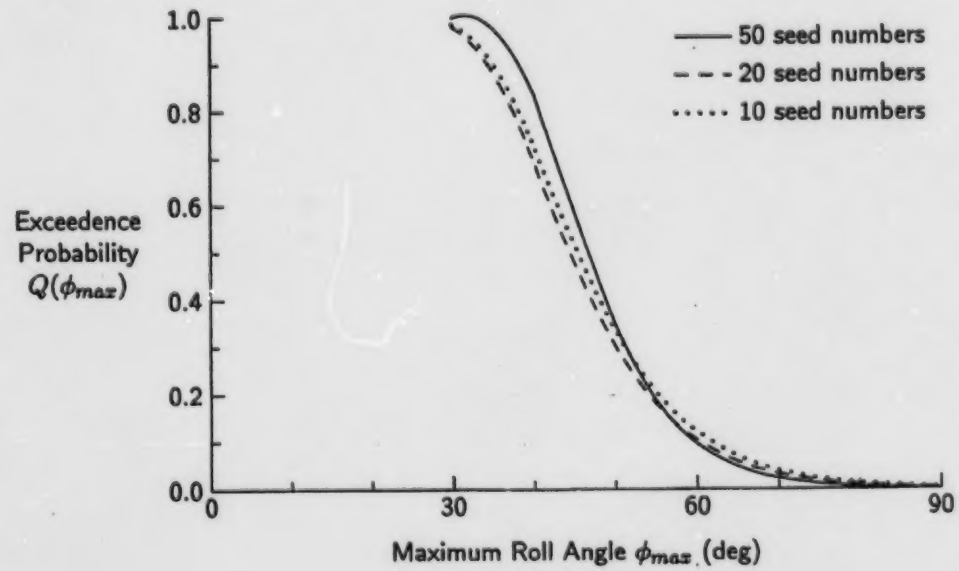

Figure 13: Roll Exceedence Probability Versus Roll Angle for Different Numbers of Seeds, 1 Hour Simulations, $\beta = 60$ degrees, $T_p = 12.4$ s, $H_s = 9.5$ m

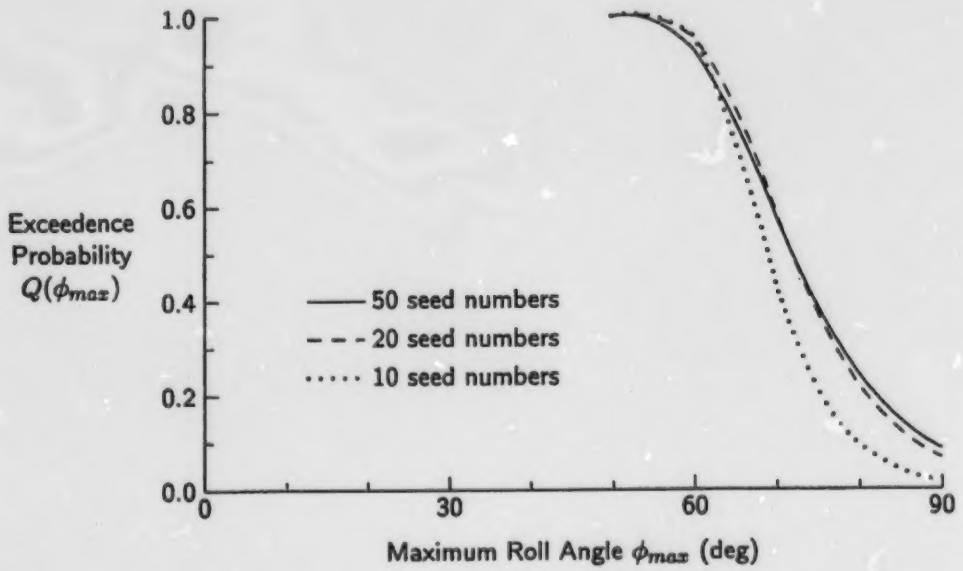

Figure 14: Roll Exceedence Probability Versus Roll Angle for Different Numbers of Seeds, 1 Hour Simulations, $\beta = 60$ degrees, $T_p = 12.4$ s, $H_s = 11.5$ m

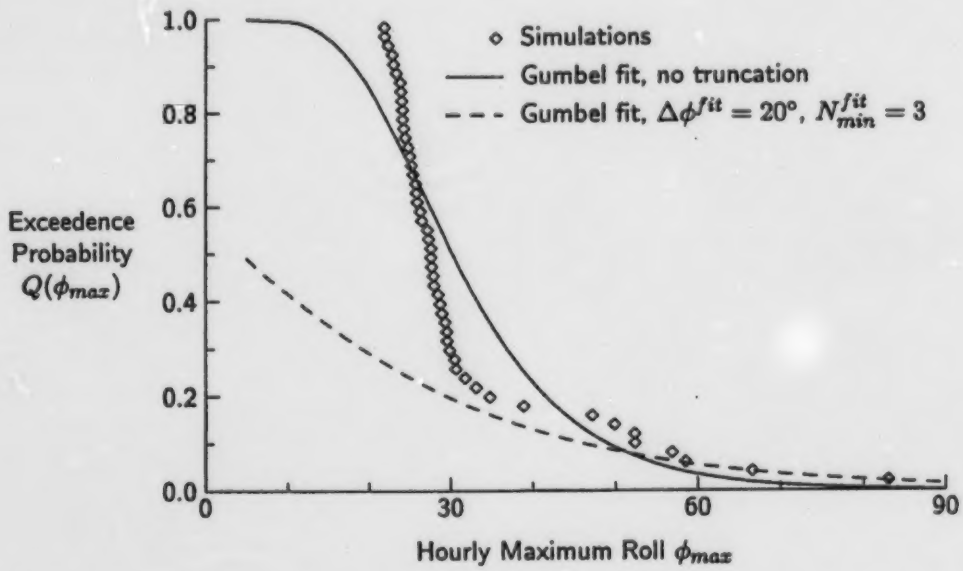

Figure 15: Roll Exceedence Probability Versus Roll Angle, 1 Hour Simulations, $\beta = 30$ degrees, $T_p = 12.4$ s, $H_s = 9.5$ m

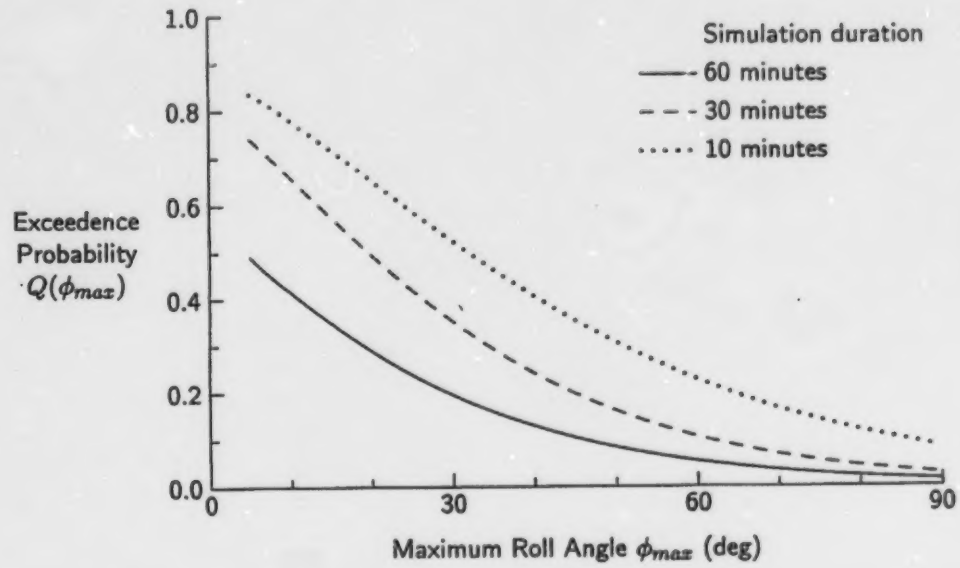

Figure 16: Hourly Roll Exceedence Probability Versus Roll Angle from Different Simulation Durations, 50 Realizations, $\beta = 30$ degrees, $T_p = 12.4$ s, $H_s = 9.5$ m

ϕ_i^{fit} with associated exceedence probabilities Q_i^{fit}. This vector does not include maximum roll angles $\geq \phi_{limit}$, the limit of valid roll angles (90 degrees for Fredyn),

2. Examine the smallest maximum roll angle ϕ_N^{fit}, and discard if $(\phi_1^{fit} - \phi_N^{fit}) > \Delta\phi^{fit}$ and $N^{fit} > N_{min}^{fit}$,
3. Repeat step 2 if possible,
4. Apply Gumbel fit to remaining N^{fit} values for ϕ_i^{fit} and Q_i^{fit}.

Figure 15 shows Gumbel fits based on all simulation values and for a fit range $\Delta\phi^{fit}$ of 20 degrees and minimum number of fit values N_{min}^{fit} of 3. The limited fit range of 20 degrees leads to a much better fit of roll exceedence probabilities for higher roll angles, which are of greatest interest for ship capsize. The truncated Gumbel fit in Figure 15 significantly underpredicts exceedence probabilities for roll angles below 50 degrees; however, this underprediction at lower roll angles is quite acceptable because only higher roll angles (e.g. > 60 degrees) are of interest when evaluating capsize risk.

Figures 16 and 17 show fitted Gumbel distributions based on 20 degree fit ranges. Figure 16 indicates that simulation durations of 10 and 30 minutes result in significant overpredictions of hourly roll exceedence probabilities. For one hour simulation durations, Figure 17 shows that 20 seed numbers give results very similar to 50 seed numbers for higher roll angles, while 10 seed numbers give overprediction of roll exceedence probabilities for higher roll angles.

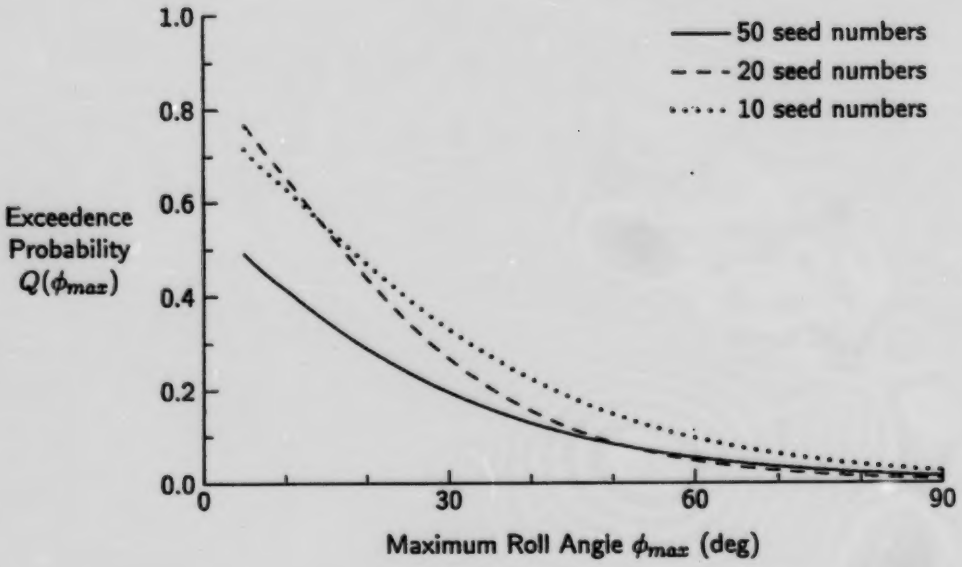

Figure 17: Roll Exceedence Probability Versus Roll Angle for Different Numbers of Seeds, One Hour Simulations, $\beta = 30$ degrees, $T_p = 12.4$ s, $H_s = 9.5$ m

6 Example Risk Assessment for Canadian Patrol Frigate

Risk assessments have been performed to evaluate the hourly capsize probability for a Canadian Patrol Frigate operating throughout the year in the North Atlantic. The risk assessments use the following three different combinations of number of wave phase seeds and simulation duration:

1. 10 wave phase seed numbers and 30 minute duration,
2. 20 wave phase seed numbers and 10 minute duration,
3. 10 wave phase seed numbers and 10 minute duration.

For fitting of Gumbel distributions, the fit range $\Delta\phi^{fit}$ is 20 degrees and the minimum number of fit points N_{min}^{fit} is 3.

6.1 Input Probability Distributions

The ship has a calm water velocity of 10 knots. Relative wave headings are assumed to be evenly distributed, with a discrete interval of 15 degrees. The assumption of evenly distributed relative wave headings is likely conservative because a ship will typically alter course in severe conditions to reduce the risk of capsize. For the discretized headings, values of 3.75 and 176.25 degrees are used to represent the heading ranges of 0-7.5 and 172.5-180 degrees respectively. Figure 18 gives the resulting discretized distribution for relative heading

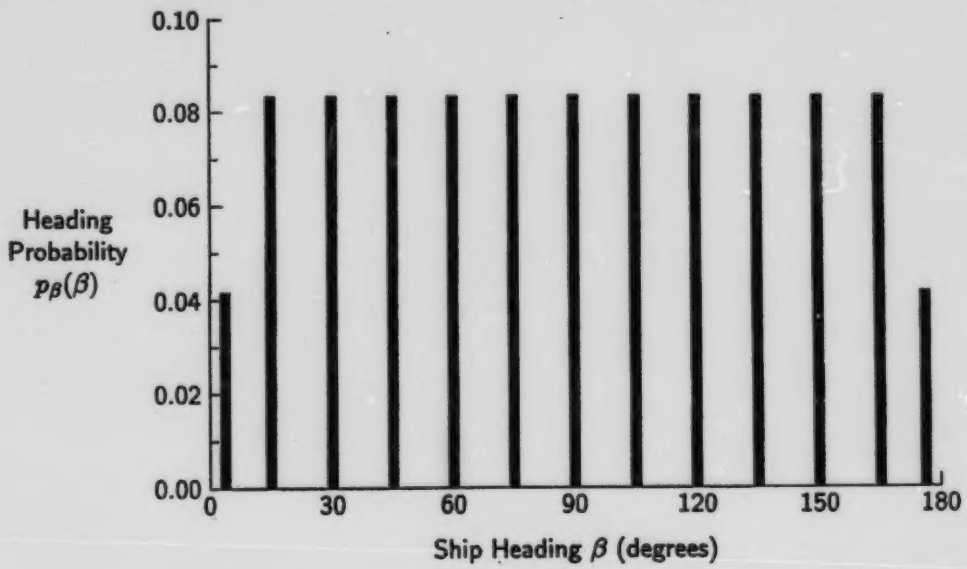

Figure 18: Probability Mass Function for Discretized Ship Headings

Annual wave climate statistics for the North Atlantic are taken from Bales [12, 16], as discussed in Section 3. Figure 19 shows the distribution of significant wave heights and Figure 20

shows the distribution of nominal wave steepnesses. Appendix E.2 gives the input wave scattergram file.

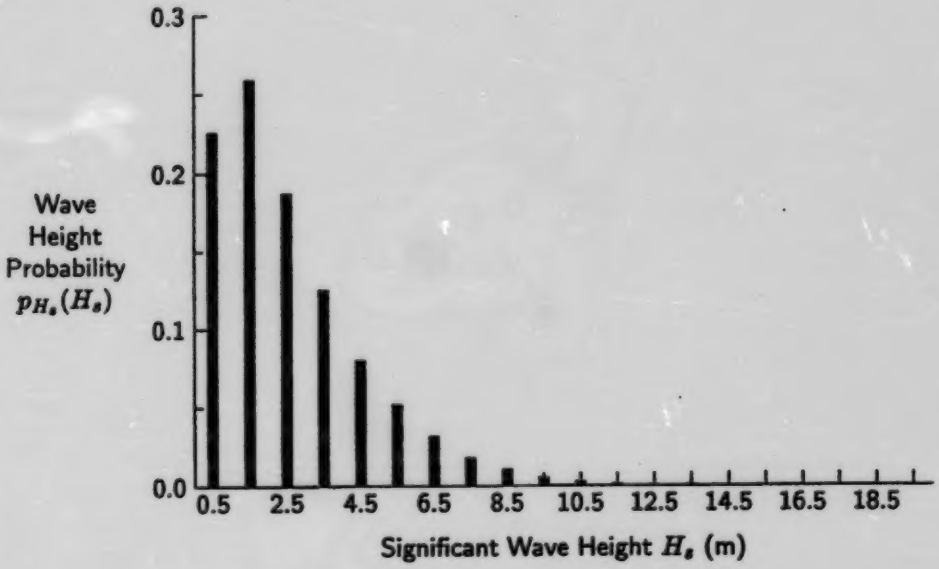

Figure 19: Distribution of Significant Wave Height for Annual North Atlantic

6.2 Computations with Pcapref

Before running program Pcapref, the programs Cdawsp and Freinp from MARIN must be run. Cdawsp performs hull geometry computations, and Freinp computes hull hydrostatic parameters. It is recommended that Fredyn also be run before Pcapref to ensure that the simulation files are properly configured.

Appendix A.2 shows the Pcapref input file for 10 seed numbers and 30 minute simulations. The sample computations were performed using ten wave phase seed numbers of 1001, 1003, ..., 1019. A Bretschneider spectrum was specified in the Fredyn base input file. Wind effects were not included.

The sample computations presented in this report were performed on a 300 MHz Dell Pentium II personal computer with a Digital Visual Fortran compiler, which runs Fredyn approximately 15 times faster than real time. For the case of 10 seed numbers and 30 minute simulations, 19 days of CPU time were required to run Pcapref for all headings and wave conditions.

6.3 Pcapref Output

Appendix B shows output from Pcapref for simulation durations of 30 minutes and 10 seed numbers. For each combination of ship speed and relative wave heading, two different tables are given with results for all combinations of significant wave height and peak wave period. The first table gives predicted capsize probabilities based on the number of observed capsizes

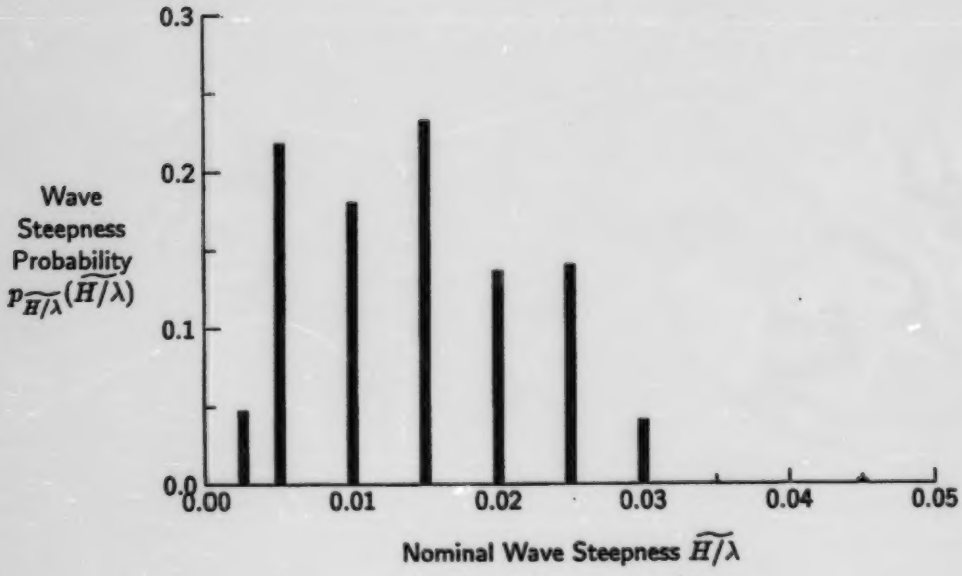

Figure 20: Distribution of Nominal Wave Steepness for Annual North Atlantic

and the second table gives the mean and standard deviation of maximum roll angle for the simulation duration. These values are based on a Gumbel fit to observed maxima. If there are less than two observed maxima below the Gumbel fit threshold value (e.g. 90 degrees), the mean and standard deviation are computed based on moments. No roll statistics are computed if the predicted linear response and nominal wave steepness are both greater than their specified threshold values.

Initial output from Pcapref showed unusual results at headings of 60 and 75 degrees for the significant wave height of 0.5 m and peak wave period of 3.2 s (nominal wave steepness of 0.03). At both of these headings, approximately 90 percent of maximum roll angles were less than 3 degrees, while approximately 10 percent of maximum roll angles were between 20 and 50 degrees. The abnormally high roll angles predicted by Fredyn have never been observed under similar experimental conditions and were likely due to numerical instabilities in Fredyn. Consequently, these large roll angles were manually corrected in the output from Pcapref.

6.4 Computations with Pcapsize2

Once initial computations have been completed with Pcapref, program Pcapsize2 can be run to determine capsize probabilities. Pcapsize2 typically runs very quickly (within seconds). Appendix C.1 describes the input for Pcapsize2 and Appendix C.2 gives a sample input file. The main potential source of failure when running Pcapsize2 is if the specified Pcapref output data file does not include simulation results for the specified conditions.

6.5 Output from Pcapsize2

Appendix D gives sample output from Pcapsize2 using 30 minute simulation durations from Pcapref. For each speed and heading combination, the program gives predicted capsize probability and maximum roll statistics. All output values are for the specified seaway duration and are based on Gumbel fits to simulation data from Pcapref. An asterisk to the right of output statistics indicates a poor Gumbel fit over the specified fit range. Output values are only given for combinations of H_s and T_p that have non-zero probabilities of occurrence.

The program output continues with summed probabilities for all conditions. Maximum roll exceedence probabilities are given for a seaway and for the specified life of the ship. The output continues with fitted Weibull, Gumbel and type II maximum distributions (see Reference 15 for roll exceedence probabilities in all seaways.

The remaining output gives conditional probabilities related to ship capsize. These conditional probabilities can be very useful for providing operational guidance to avoid dangerous conditions.

6.6 Discussion of CPF Results

The present discussion on the CPF focusses on the Pcapsize2 output in Appendix D, which incorporates results from Pcapref.

Figure 21 shows hourly exceedence probabilities, and indicates that the predicted values are insensitive to simulation duration and number of simulations. Figures 22 and 23 show annual exceedence probabilities, which show greater dependence on simulation duration and number of simulations. The results based on 10 simulations of 10 minute duration give significantly higher exceedence probabilities than the other results, suggesting that the product of simulation duration and number of simulations is a key determinant of the accuracy of the results.

In contrast to the results in Figure 23 for a Gumbel fit range $\Delta\phi^{fit}$ of 20 degrees and minimum number of fit points N_{min}^{fit} of 3, Figure 24 shows annual roll exceedence probabilities for Gumbel fits over the entire range of roll angles, and gives significantly smaller exceedence probabilities for roll angles exceeding 50 degrees. Using a Gumbel fit range of 20 degrees likely leads to better predictions of capsize probabilities because the resulting Gumbel fits are superior in vicinity of capsize roll angles.

Figures 25 to 31 show various conditional probabilities associated with ship capsize. Figures 25 and 26 shows that stern quartering and beam seas are much more likely to cause capsize than bow and head seas. Altering of course to head seas can greatly reduce capsize risk. By maintaining a heading between 135 and 180 degrees, the annual capsize risk is reduced to less than 10^{-5}. The most surprising result from Figures 25 and 26 is that the capsize risk at a heading of 120 degrees is much higher from the 30 minute simulations than from the two sets of 10 minute simulations. The much higher risk from 30 minute simulations can be traced to wave conditions of T_p = 15 s, H_s = 11.5 m, for which Table 4 gives maximum roll angles in order of wave phase seed numbers of 1001, 1003, 1005, ... For a given wave phase seed number, the maximum roll from a 30 minute simulation is greater than or equal to the maximum roll from a 10 minute simulation, as expected. For the fifth wave phase seed number, a maximum roll angle of 86 degrees occurs after more than 10 minutes have passed. All other maximum roll angles are less than 30 degrees. The sample output from Pcapsize2 given in Appendix D indicates that a poor Gumbel fit occurs for the 30 minute simulations due to the outlier point

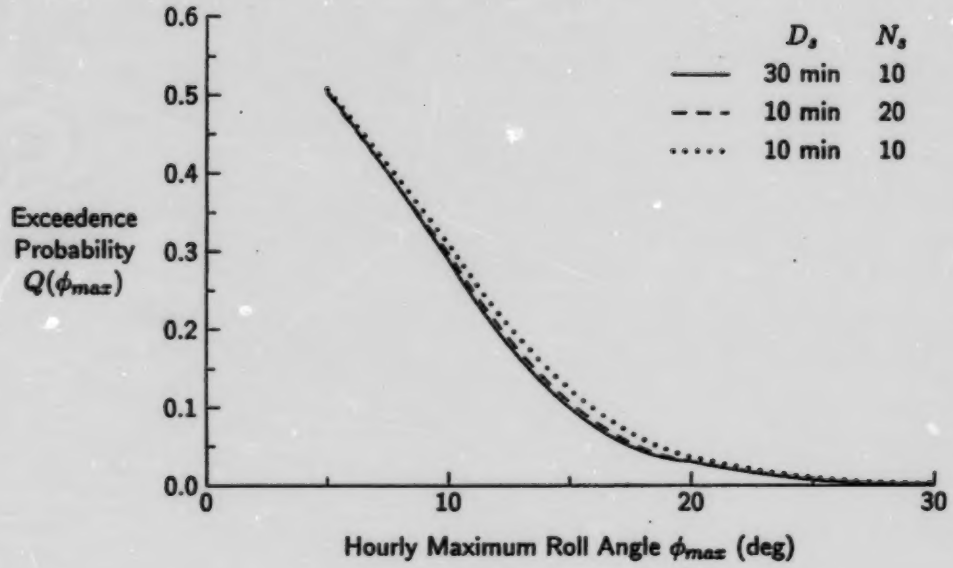

Figure 21: Exceedence Probabilities for Hourly Maximum Roll

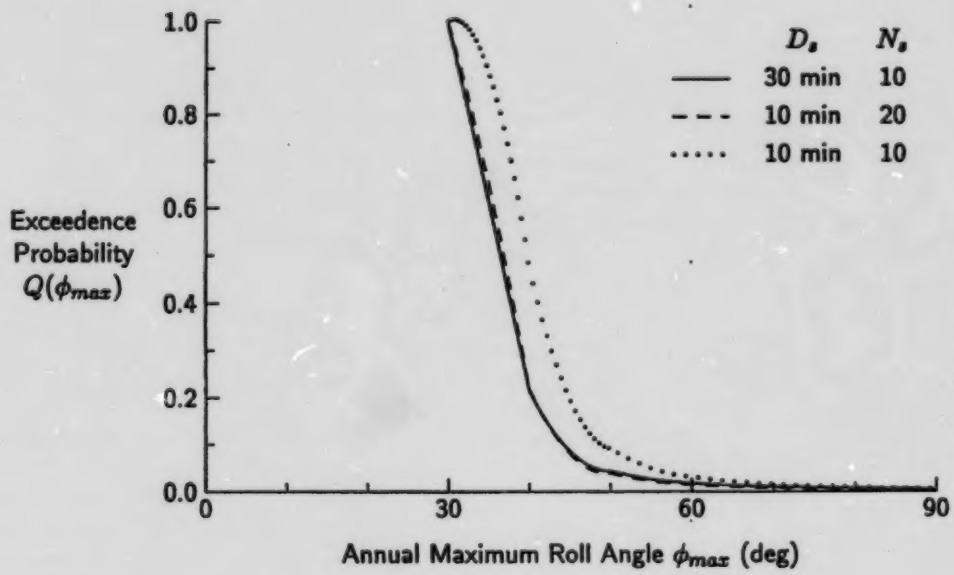

Figure 22: Exceedence Probabilities for Annual Maximum Roll

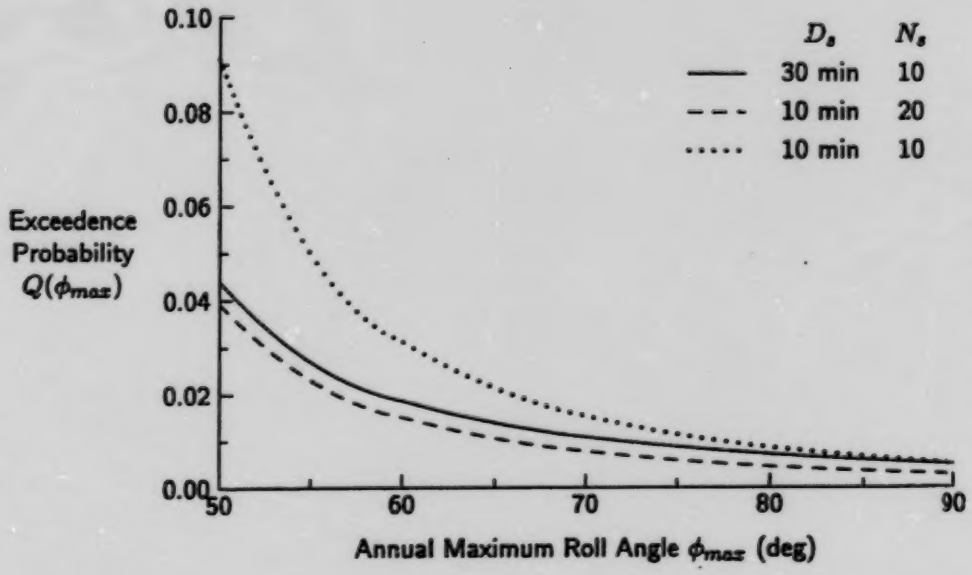

Figure 23: Exceedence Probabilities for Annual Maximum Roll, High Roll Angles

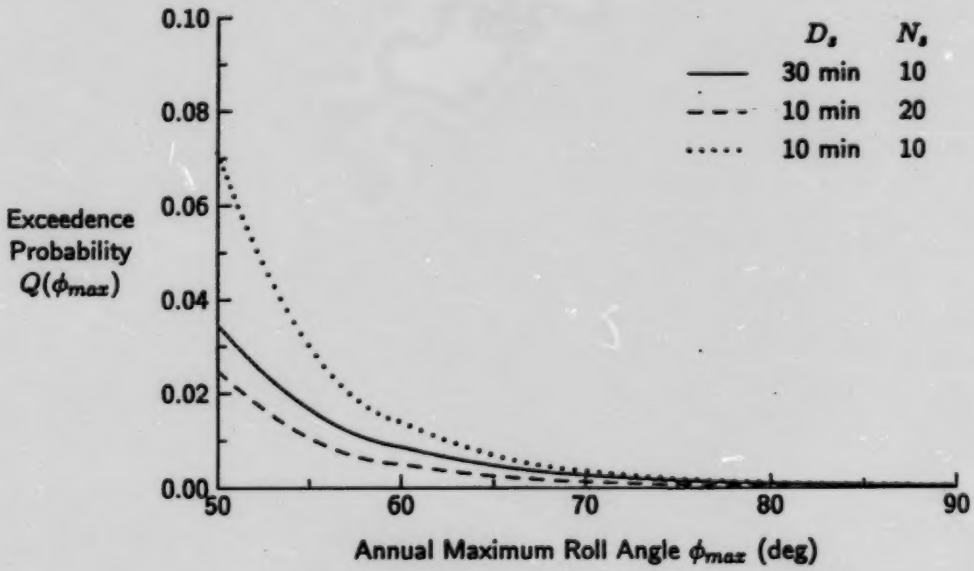

Figure 24: Exceedence Probabilities for Annual Maximum Roll, Full Gumbel Fit Range

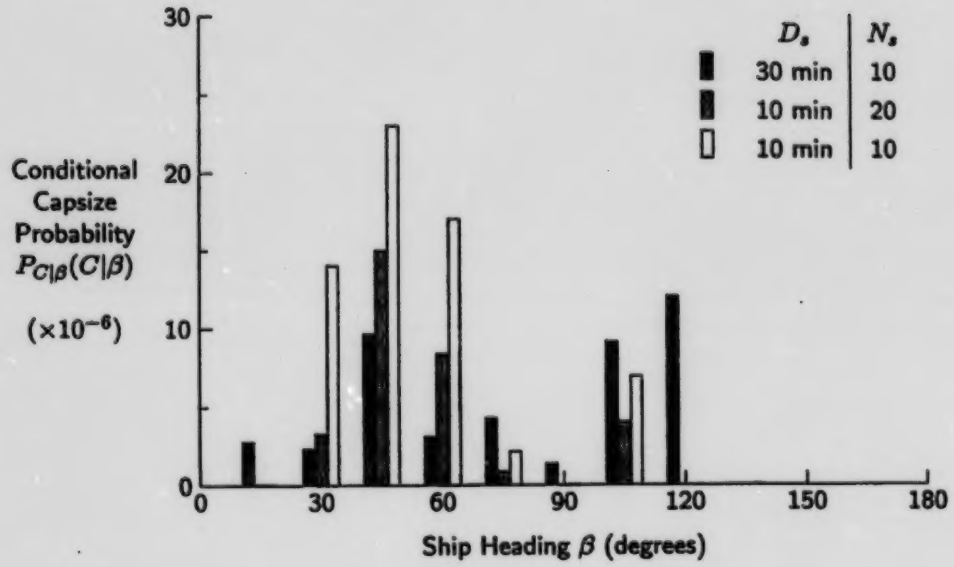

Figure 25: Conditional Hourly Probability of Capsize Given Heading

of 86 degrees. This case illustrates the importance of simulation duration and number of seeds being sufficiently large when outlier maximum roll angles occur.

Due to the large sensitivity of capsize risk to simulation duration for a heading of 120 degrees, additional computations were performed as indicated in Table 5. These results confirm that the simulation durations of 10 minutes give severe underpredictions of annual capsize risk at this heading. The results based on simulation durations of 30 and 60 minutes give similar values for annual capsize risk.

The conditional probabilities related to significant wave height are shown in Figures 27 and 28. In Figure 27, the dependence of wave period on wave height accounts for capsize probability to not necessarily increase with increasing wave height. The significant difference among 10 minute and 30 minute simulations for a wave height of 11.5 m is due to the results in Table 4

Table 4: Maximum Roll Angles from Simulations, $\beta = 120$ degrees, $T_p = 15$ s, $H_s = 11.5$ m

Simulation Duration T_s (minutes)	Number of Seeds N_s	Maximum Roll Angles ϕ_{max} (deg)
30	10	26, 25, 25, 25, 86, 27, 26, 27, 26, 27
10	20	23, 23, 21, 25, 22, 27, 25, 22, 26, 23, 21, 21, 26, 23, 23, 23, 21, 24, 22, 26
10	10	23, 23, 21, 25, 22, 27, 25, 22, 26, 23

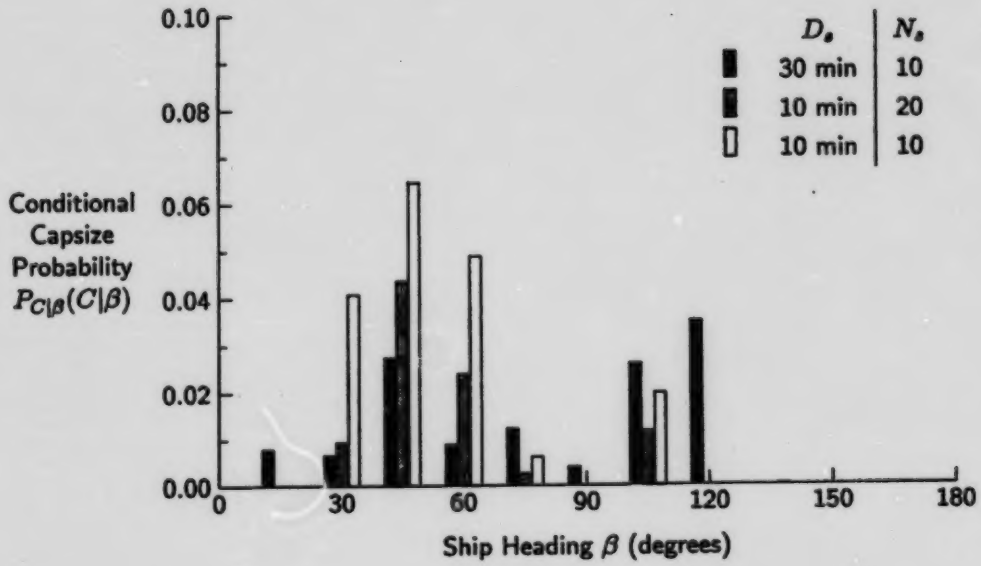

Figure 26: Conditional Annual Probability of Capsize Given Heading

Table 5: Annual Capsize Risk for 120 Degree Heading

Simulation Duration T_s (minutes)	Number of Seeds N_s	Annual Capsize Risk
10	10	8.1×10^{-6}
10	20	0.3×10^{-6}
30	10	0.035
30	20	0.019
60	10	0.019

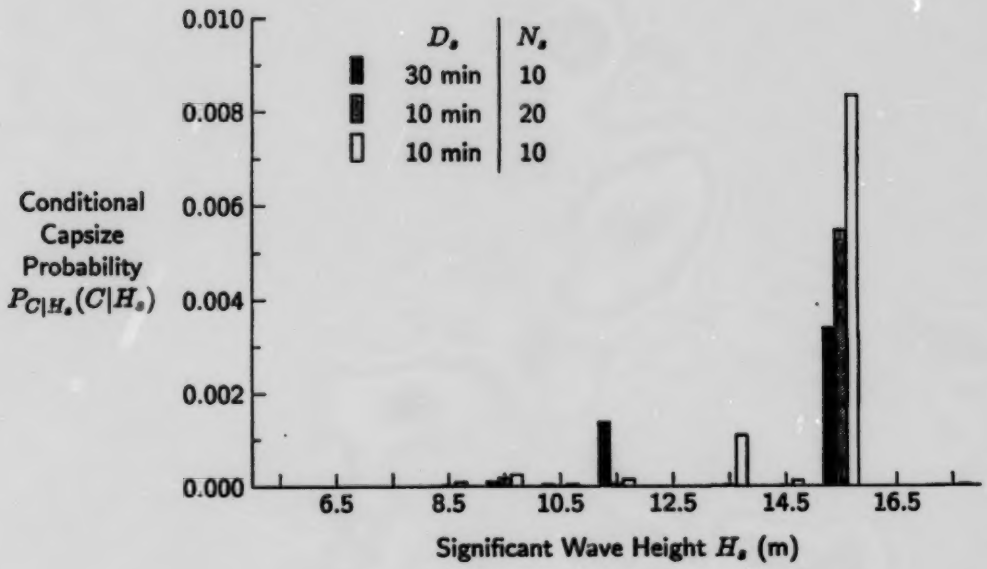

Figure 27: Conditional Hourly Probability of Capsize Given Wave Height

discussed in the previous paragraph. For a simulation duration of 30 minutes and wave height of 11.5 m, the high capsize risk is due to a simulation maximum roll angle of 86 degrees for a wave period of 15 s, as given in Table 4. Differences between Figures 27 and 28 arise because lower wave heights occur much more frequently than higher wave heights. Figure 28 indicates that capsize risk can be significant for wave heights as low as 6.5 m.

Figure 29 gives conditional probabilities of wave period given capsize. Wave periods greater than 18 s give waves of low steepness, resulting in negligible capsize risk. Figures 30 and 31 give conditional probabilities relating to nominal wave steepness. Although Figure 20 indicates that the majority of wave conditions have nominal wave steepnesses of 0.02 and less, Figures 30 and 31 indicate that capsize risk is only appreciable for wave steepnesses of 0.025 and greater.

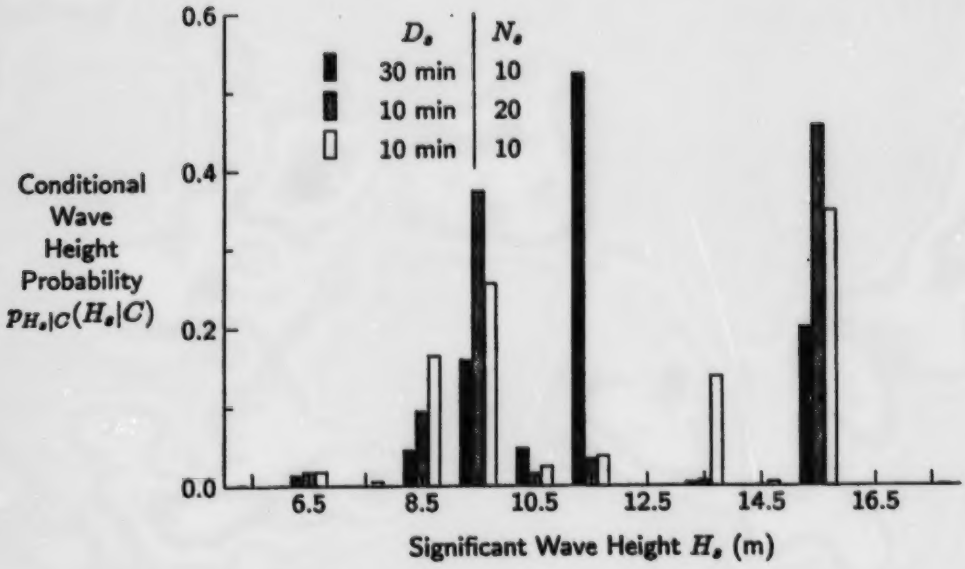

Figure 28: Conditional Probability of Significant Wave Height Given Capsize

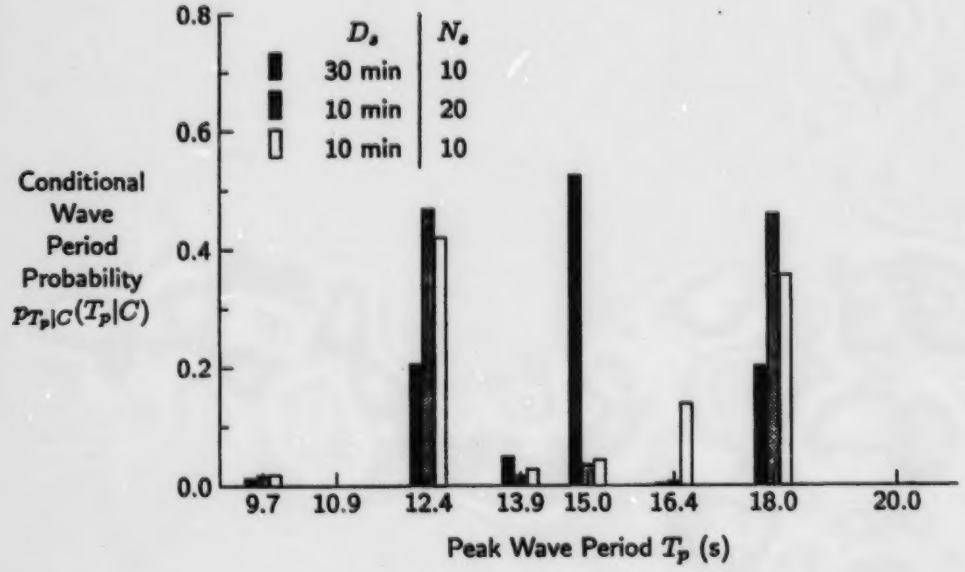

Figure 29: Conditional Probability of Peak Wave Period Given Capsize

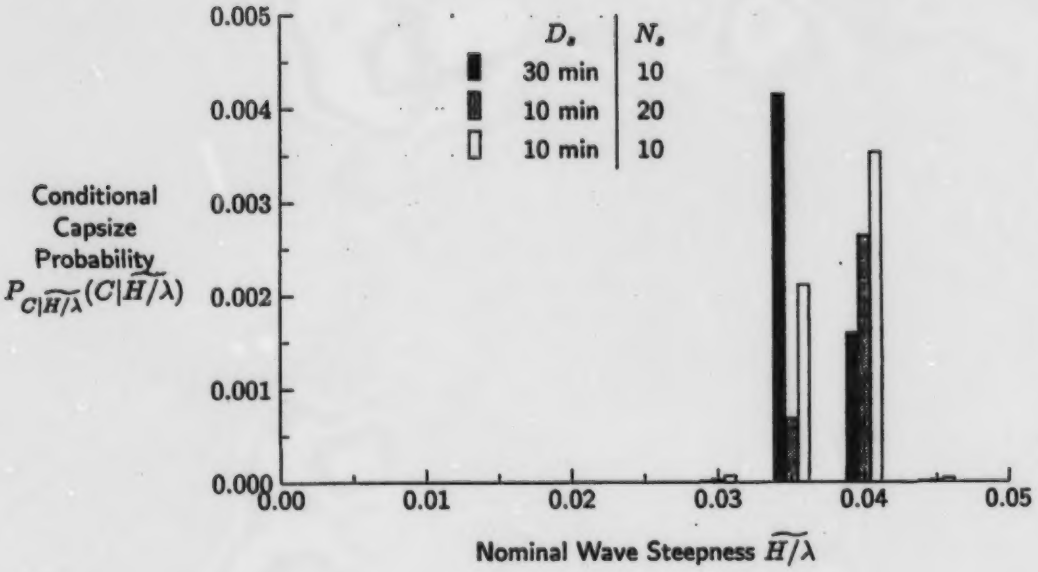

Figure 30: Conditional Hourly Probability of Capsize Given Nominal Wave Steepness

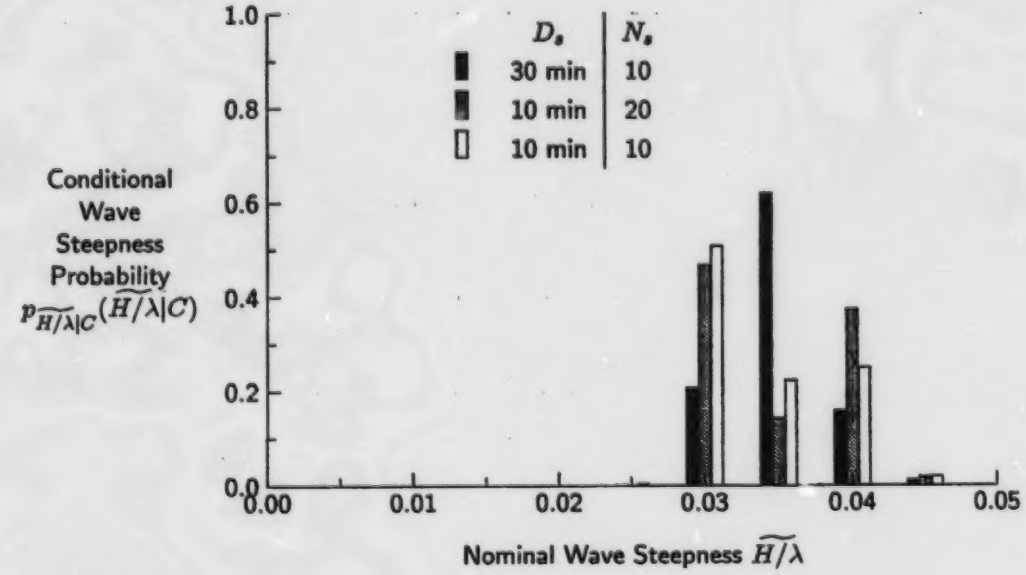

Figure 31: Conditional Probability of Nominal Wave Steepness Given Capsize

7 Recommendations for Future Work

Further research is recommended before application of the current risk analysis procedure to routine design and operation. The procedure should be revised to include the influence of ship operator actions to avoid dangerous conditions. For example, a ship captain will usually alter speed and heading in severe seas. The following equation could be used to include alteration of speed and course in response to significant wave height:

$$Q_{\phi_{max,D}}(\phi_{max,D}) = \sum_{i=1}^{N_{V_s}} \sum_{j=1}^{N_\beta} \sum_{k=1}^{N_{H_s}} \sum_{l=1}^{N_{T_p}} p_{V_s|H_s}(V_{s-i}|V_s)\, p_{\beta|H_s}(\beta_j|H_s)\, p_{H_s,T_p}(H_{s-k}, T_{z-l}) \times Q_{\phi_{max,D}|V_s,\beta,H_s,T_p}(\phi_{max,D}|V_{s-i}, \beta_j, H_{s-k}, T_{p-l}) \quad (7.1)$$

Ongoing examination of ship operational profiles, such as Reference 22, will provide necessary data on the conditional distributions of ship speed and heading.

The accuracy of capsize risk predictions depends on the accuracy of the input wave statistical data. Wave data from Bales [12] and BMT Global Wave Statistics [13] give significantly different values for nominal wave steepnesses. Although it appears that the BMT data likely underestimate wave periods, the validity of available wave data sources should be investigated in detail.

Application of the current procedure to ship design and operation requires that acceptable risk levels be specified. Such risk levels could be chosen by examining risk levels associated with other hazards, and by benchmarking of capsize risk levels for ships which have had long histories of safe operation.

The existence of outlier points with high maximum roll angles highlights the importance of using a sufficient number of wave phase seeds and sufficient simulation duration. For each case with outlier points, improved accuracy of capsize risk could be achieved by performing an increased number of simulations.

For practical application, the current procedure requires several weeks of computation time on a desktop computer. This computation time could be reduced significantly by using parallel processing to run several time domain simulations simultaneously. Implementation of a parallel processing capability would be worthwhile if the code were going to be used frequently.

Simulations for a significant wave height of 0.5 m and peak wave period of 3.2 s indicate that unrealistically high maximum roll angles can occur for certain wave phase seed numbers. This problem is likely due to numerical instabilities in Fredyn and should be addressed.

8 Conclusions

A new procedure has been developed for determining capsize risk of an intact ship in waves. The procedure considers the joint probability distribution of significant wave height and peak wave period, which is available from several sources.

For a given combination of ship speed, heading, wave height, and wave period, the dependence of maximum absolute roll angle on wave process realization can be efficiently modelled by fitting a Gumbel distribution to maximum roll angles from simulations using different wave phase seed numbers. In a minority of cases where outlier points of high maximum roll angle occur, a Gumbel distribution can be fitted to an upper range of roll angles, which is of greatest

importance for assessing capsize risk. The properties of the Gumbel distribution also permit using simulations of shorter duration (e.g. thirty minutes) for predicting properties of longer duration (e.g. one hour). The accuracy of predicted capsize risk increases with increasing simulation duration and number of wave phase seeds. It is recommended that a minimum of 10 seeds and a minimum simulation duration of 30 minutes be used for assessing capsize risk for a given combination of ship speed, heading, wave height, and wave period.

The risk analysis procedure has been implemented using the Fredyn ship motion program, which uses a time domain strip theory approach. A capsize risk analysis for one ship speed, all headings, and all wave conditions requires approximately 20 days of computation time on a personal computer, which is likely acceptable for final ship design.

Example computations for a CPF travelling at 10 knots in the North Atlantic give an annual capsize risk of 0.01 when all headings are assumed to have equal probability of occurrence. By restricting heading to between 135 and 180 degrees (bow to head seas), the predicted annual capsize risk is reduced to 10^{-5}.

Ongoing work will refine the risk analysis procedure such that it can be used for ship design and operation. Ship operational profile data will be used to quantify the influence of capsize avoidance action. Future work will also examine the selection of appropriate target risk levels.

A Input for Program Pcapref

A.1 Description of Pcapref Input Records

Detailed descriptions of Pcapref input records are given below. Each new input record or sub-record corresponds to a new file line. The format of the input file may be adjusted by inserting extra blanks between any numeric data, and by placing data from within any numeric record on separate lines; however, separate records cannot be combined on a single line. Character strings specifying program options must be uppercase, as shown below.

Record (a), Eighty Character Title
TITLE (char*80)

TITLE — Alphanumeric title (maximum of 80 characters) which is written on output.

Record (b), Fredyn Base Input File
FRBASEINFILE (char*80)

FRBASEINFILE — Name of base Fredyn input file (maximum of 80 characters). Pcapref reads this file and then writes a new Fredyn input file with modified values for ship speed, heading, and wave parameters.

Record (c), Fredyn Input File
FRINFILE (char*80)

FRINFILE — Name of Fredyn input file (maximum of 80 characters) that is created by Pcapref for Fredyn parametric simulations. This file name is typically "fredyn.inp".

Record (d), Fredyn Output File
FROUTFILE (char*80)

FROUTFILE — Name of Fredyn output file (maximum of 80 characters) from parametric simulations. This file name is typically "fredyn.out".

Record (e), Fredyn Time Series Data File
FRDATFILE (char*80)

FRDATFILE — Name of Fredyn output time series data file (maximum of 80 characters) from parametric simulations. This file name is typically "fredyn.dat".

Record (f), Number of Ship Speeds
NSPEED (1 integer)

NSPEED — Number of ship speeds (maximum 10).

Note: Record (f) must be followed by NSPEED records (f1).

Record (f1), Ship Speed and Propeller RPM Guess
SPEEDKNOT(I), NPGUESS(I) (2 reals)

SPEEDKNOT(I) Ship speed in calm water (knots).

NPGUESS(I) Guess for propeller RPM in calm water. An iterative procedure is used to determine the actual propeller RPM for SPEEDKNOT(I).

Record (g), Number of Ship Headings
NHEAD (1 integer)

NHEAD Number of ship headings (maximum 36).

Record (g1), Ship Headings
HEAD(I) (NHEAD reals)

HEAD(I) Desired ship headings (180 degrees for head seas).

Record (h), Number of Significant Wave Heights
NHSIG (1 integer)

NHSIG Number of significant wave heights (maximum 20).

Record (h1), Significant Wave Heights
HSIG(I) (NHSIG reals)

HSIG(I) Significant wave height (m).

Record (i), Number of Peak Wave Periods
NTPWAVE (1 integer)

NTPWAVE Number of peak wave periods (maximum 20).

Record (i1), Peak Wave Periods
TPWAVE(I) (NTPWAVE reals)

TPWAVE(I) Peak wave period (s).

Record (j), Wave Phase Seed Numbers
NSEED, ISEEDMIN, ISEEDINC (3 integers)

NSEED Number of wave phase seed numbers (maximum 999). To obtain a reasonable compromise between accuracy and CPU time, this value should typically be between 9 and 50.

ISEEDMIN Minimum wave phase seed number (maximum 99999). This should typically be an odd number greater than 100.

ISEEDINC Wave phase seed increment (maximum 9999). This should typically be an even number such that all seed numbers are odd numbers.

Record (k), Wind Option
WINDFLAG (char*20)

WINDFLAG Option for wind computations. The three possible inputs are:

NOWIND	No wind effects.
WAVEWIND	Wind collinear with waves.
BEAMWIND	Beam wind within 90 degrees of waves.

Record (k1), Wind Speed Coefficients
Read only if WINDFLAG is equal to WAVEWIND or BEAMWIND in Record (k).
AWIND, BWIND, CWIND (3 reals)
Wind speed is assumed to be a function of wave height as follows:

$$\overline{U}_{10m} = A H_s^2 + B H_s + C$$

where $\overline{U}_{10m}$ is wind speed (m/s) and H_s is significant wave height (m).

AWIND Wind coefficient A (/(ms)).

BWIND Wind coefficient B (/s).

CWIND Wind coefficient C (m/s).

Record (k2), Wind Gust Seed Numbers
Read only if WINDFLAG is equal to WAVEWIND or BEAMWIND in Record (k).
ISEEDWINDMIN, ISEEDWINDINC (2 integers)

ISEEDWINDMIN Minimum wind gust phase seed number (maximum 99999). This should typically be an odd number greater than 100.

ISEEDWINDINC Wind gust phase seed increment (maximum 9999). This should typically be an even number such that all seed numbers are odd numbers.

Record (l), Simulation Time Parameters
TSAMPLE, TSTAT, TINS (3 reals)

TSAMPLE Simulation sample time (s). This should typically be between 600 (10 minutes) and 3600 (1 hour).

TSTAT Simulation delay before sampling. A value of 20 seconds is appropriate.

TINS Duration of cosine-type ramp function applied to excitation forces. A value of 20 seconds is appropriate.

Record (m), Linear Response Parameters
ROLLLINLIMIT, HSREFLIN (2 reals)

ROLLLINLIMIT Maximum absolute value for linear roll response (degrees). A value of 15 degrees is recommended.

HSREFLIN Reference significant wave height for determining maximum roll angle using linearity assumption. A value of approximately 1 m is recommended.

Record (n), Capsize Roll Angle
ROLLCAPSIZE (1 real)

ROLLCAPSIZE Roll angle for capsize (degrees). For the current version of Fredyn, this has a maximum value of 90 degrees. The angle of downflooding is often a suitable value.

Record (o), Nominal Wave Steepness Limit
WAVESTEEPHSTPMAX (1 real)

WAVESTEEPHSTPMAX Limit on nominal wave steepness $2\pi H_s/(gT_p^2)$ for simulations. Data from Bales indicate that 0.06 is a suitable value. Fredyn can experience numerical integration problems at higher nominal steepnesses.

Record (p), Old Data Flag
OLDDATAFLAG (char*20)

OLDDATAFLAG Option for using data from previous program run. The two options are:

NOOLDDATA No old data available.

USEOLDDATA If available, use data from previous program run.

Record (p1), Old Data File
Read only if OLDDATAFLAG is equal to USEOLDDATA in Record (p).
OLDDATAFILE (char*80)

OLDDATAFILE File with data from previous program run.

A.2 Sample Pcapref Input

```
CPF, 30 minute simulations, 20 seeds
fredynbase.inp                              <----- Fredyn base input file
fredyn.inp                                  <----- Fredyn input file
fredyn.out                                  <----- Fredyn output file
fredyn.dat                                  <----- Fredyn data file
1                   <---- Number of ship speeds
10.0, 67.5          <---- Ship speed (knots), guess for propeller RPM
13                  <---- Number of ship headings
3.75 15.0 30.0 45.0 60.0 75.00 90.0 105.0 120.0
135.0 150.0 165.0 176.25 <---- Ship heading (deg)
20                  <---- Number of wave heights
0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.50
10.5 11.5 12.5 13.5 14.5 15.5 16.5 17.5 18.5 19.50    <---- Sig wave height (m)
15                  <--- Number of peak wave periods
3.2 4.5 6.3 7.5 8.5 9.7 10.9 12.4 13.9
15.0 16.4 18.0 20.0 22.5 25.7   <---- Peak crossing wave period (s)
20, 1001, 2           <----- Number of seed numbers, lowest seed number, inc
NOWIND                <----- Wind flag
1800.0, 20.0, 20.0    <----- Duration, delay, ramp
15.0, 0.5             <----- Linear roll limit, Hs ref
70.0                  <----- Capsize roll angle
0.06                  <----- Max wave steepness based on Hs and Tp
NOOLDDATA             <----- Old data flag
```

B Sample Output for Pcapref

```
Output from program PCAPREF, Capsize risk given environment and operational conditions
Defence Research Establishment Atlantic
Program Version 1.0 - November 1998

PCAPREF Run Title:
CPF, 30 minute simulations, 10 seeds, 0.001 tolerance, corrected data
15:23:36 03-Feb-1999


**************** ECHO OF USER INPUT ****************

Base FREDYN input file       : fredynbase.inp
FREDYN input file            : fredyn.inp
FREDYN main output file      : fredyn.out
FREDYN time series data file : fredyn.dat

 1 ship speeds
Speed (knots)  Propeller RPM guess
   10.00        67.50

13 ship headings
Heading (deg)
    3.75
   15.00
   30.00
   45.00
   60.00
   75.00
   90.00
  105.00
  120.00
  135.00
  150.00
  165.00
  176.25

20 significant wave heights
Hs (m)
    0.50
    1.50
    2.50
    3.50
    4.50
    5.50
    6.50
    7.50
    8.50
    9.50
   10.50
   11.50
   12.50
   13.50
   14.50
   15.50
   16.50
   17.50
   18.50
   19.50
```

```
15 peak wave periods
TP (s)
    3.20
    4.50
    6.30
    7.50
    8.50
    9.70
   10.90
   12.40
   13.90
   15.00
   16.40
   18.00
   20.00
   22.50
   25.70


Seed numbers for random waves
  Number of seeds        :       20
  Minimum seed number    :     1001
  Seed number increment  :        2


Wind flag WINDFLAG : NOWIND                - No wind

Time parameters (seconds)
  Simulation sample time          :   1800.00
  Delay before sampling           :     20.00
  Force ramp time                 :     20.00

Linear roll response parameters
  Maximum roll angle for linear response (deg)  :      15.00
  Reference wave height for linear response (m) :       0.50

Maximum roll response parameters
  Capsize roll angle (deg)                      :      70.00

Limit on wave steepness
  Limit is based on significant wave height Hs and peak wave period TP
  Limit :      0.060 (height/length)

Old data flag OLDDATAFLAG : USEOLDDATA
Old data file : pcref30min.dat
```

****** Capsize probabilities and maximum roll for given conditions ******

Calm water ship speed : 10.00 knots (5.15 m/s)
Propeller RPM : 67.50
Heading : 3.75 degrees

Simulation duration for roll statistics : 1800.00 seconds
A blank cell means value not computed

Observed capsize probability for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.5			0	0	0	0	0	0	0	0	0	0	0	0	0
14.5			0	0	0	0	0	0	0	0	0	0	0	0	0
15.5			0	0	0	0	0	0	0	0	0	0	0	0	0
16.5			0	0	0	0	0	0	0	0	0	0	0	0	0
17.5			0	0	0	0	0	0	0	0	0	0	0	0	0
18.5			0	0	0	0	0	0	0	0	0	0	0	0	0
19.5			0	0	0	0	0	0	0	0	0	0	0	0	0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	1, 0	1, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0
1.5	3, 0	2, 0	1, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0
2.5	6, 0	3, 0	1, 0	1, 0	1, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	1, 0	1, 0	1, 0
3.5	8, 0	4, 0	2, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0
4.5	10, 0	5, 0	2, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0
5.5	12, 0	6, 0	3, 0	2, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	2, 0
6.5	14, 0	7, 0	3, 0	2, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	2, 0	2, 0
7.5		8, 0	4, 1	2, 0	2, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	2, 0	2, 0	2, 0
8.5		9, 0	5, 1	2, 0	2, 0	2, 0	1, 0	1, 0	1, 0	2, 0	1, 0	2, 0	2, 0	2, 1	2, 0
9.5		10, 0	5, 1	3, 1	2, 0	2, 0	2, 0	1, 0	1, 0	2, 0	2, 0	2, 0	2, 0	2, 1	3, 0
10.5		11, 0	6, 1	3, 1	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	3, 1	3, 0
11.5		12, 1	6, 1	3, 1	3, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	3, 1	3, 0
12.5		14, 1	7, 1	4, 1	3, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	3, 0	3, 1	4, 0
13.5			7, 1	4, 1	3, 0	3, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	3, 0	3, 1	4, 0
14.5			8, 1	4, 1	3, 0	3, 1	2, 0	2, 0	2, 0	3, 0	2, 0	3, 0	3, 0	3, 1	4, 1
15.5			8, 1	4, 1	3, 0	3, 1	3, 1	2, 0	2, 0	3, 0	3, 0	3, 0	3, 0	4, 1	4, 1
16.5			9, 1	5, 1	4, 0	3, 1	3, 1	2, 0	2, 0	3, 0	3, 1	3, 0	4, 1	4, 1	5, 1
17.5			9, 1	5, 1	4, 0	3, 1	3, 1	3, 0	3, 0	3, 0	3, 1	3, 1	4, 1	4, 1	5, 1
18.5			10, 1	5, 1	4, 0	4, 1	3, 1	3, 0	3, 0	3, 0	3, 1	3, 1	4, 1	4, 1	5, 1
19.5			10, 1	6, 1	4, 0	4, 1	3, 1	3, 0	3, 0	3, 0	3, 1	3, 1	4, 1	5, 1	5, 1

****** Capsize probabilities and maximum roll for given conditions ******

Calm water ship speed : 10.00 knots (5.15 m/s)
Propeller RPM : 67.50
Heading : 15.00 degrees

Simulation duration for roll statistics : 1800.00 seconds
A blank cell means value not computed

Observed capsize probability for given conditions

	Wave Period Tp (s)													
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.5			0	0	0	0	0	0	0	0	0	0	0	0	0
5.5					0	0	0	0	0	0	0	0	0	0	0
6.5					0	0	0	0	0	0	0	0	0	0	0
7.5						0	0	0	0	0	0	0	0	0	0
8.5						0	0	0	0	0	0	0	0	0	0
9.5							0	0	0	0	0	0	0	0	0
10.5							0	0	0	0	0	0	0	0	0
11.5								0	0	0	0	0	0	0	0
12.5								0.200	0	0	0	0	0	0	0
13.5								0.500	0.100	0	0	0	0	0	0
14.5									0.200	0	0	0	0	0	0
15.5									0.800	0	0	0	0	0	0
16.5									0.800	0.300	0.100	0	0	0	0
17.5									1.000	0.800	0.100	0	0	0	0
18.5										0.900	0.400	0	0	0	0
19.5										0.800	0.700	0.100	0	0	0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)													
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	2, 0	2, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	0, 0	0, 0	0, 0	0, 0
1.5	7, 0	5, 0	4, 0	4, 0	4, 0	4, 0	3, 0	3, 0	2, 0	2, 0	2, 0	1, 0	1, 0	0, 0	0, 0
2.5	12, 1	8, 0	7, 1	7, 1	6, 1	6, 1	6, 1	5, 1	4, 1	3, 0	3, 0	2, 0	1, 0	1, 0	1, 0
3.5		12, 1	10, 1	10, 1	9, 1	9, 1	8, 1	7, 1	6, 1	5, 1	4, 0	3, 0	2, 1	1, 0	1, 0
4.5			12, 1	12, 1	12, 1	11, 1	10, 1	9, 1	7, 1	6, 1	5, 0	3, 0	2, 1	1, 0	1, 0
5.5					14, 1	13, 2	13, 2	10, 2	9, 1	8, 1	6, 1	4, 1	2, 1	1, 0	1, 0
6.5					15, 1	13, 1	12, 1	11, 1	10, 1	9, 1	7, 1	5, 1	3, 1	1, 0	2, 0
7.5						13, 1	14, 1	11, 1	12, 2	10, 1	8, 1	5, 1	3, 1	2, 0	2, 0
8.5						20,14	18, 5	13, 1	12, 1	12, 1	9, 1	6, 1	4, 1	2, 0	2, 0
9.5							23, 9	17, 4	14, 3	12, 2	10, 1	7, 1	4, 1	2, 0	2, 0
10.5							27, 5	23, 6	17, 5	14, 5	11, 1	8, 1	5, 2	2, 0	2, 0
11.5								31, 6	22,10	18, 9	12, 1	8, 1	5, 2	3, 0	3, 0
12.5								52,23	27,12	20, 5	17, 5	9, 1	5, 2	3, 1	3, 0
13.5								70,16	35,18	25, 7	21, 5	10, 1	6, 2	3, 1	3, 0
14.5									48,21	32,11	27, 7	10, 1	6, 2	3, 1	3, 0
15.5									76,22	45,12	33, 6	11, 1	7, 2	3, 1	4, 1
16.5									80,15	66,17	41,14	12, 1	7, 3	4, 1	4, 1
17.5									89, 2	78,13	47,19	13, 2	8, 3	4, 1	4, 1
18.5										87, 7	67,18	34,11	8, 3	4, 1	4, 1
19.5										83,11	81,15	49,14	8, 3	4, 1	5, 1

****** Capsize probabilities and maximum roll for given conditions ******

Calm water ship speed : 10.00 knots (5.15 m/s)
Propeller RPM : 67.50
Heading : 30.00 degrees

Simulation duration for roll statistics : 1800.00 seconds
A blank cell means value not computed

Observed capsize probability for given conditions

	Wave Period Tp (s)													
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5			0	0	0	0	0	0	0	0	0	0	0	0	0
4.5				0	0	0	0	0	0	0	0	0	0	0	0
5.5					0	0	0	0	0	0	0	0	0	0	0
6.5					0	0	0	0	0	0	0	0	0	0	0
7.5						0	0	0	0	0	0	0	0	0	0
8.5						0.200	0.100	0	0	0	0	0	0	0	0
9.5							0.300	0	0	0	0	0	0	0	0
10.5							0.800	0.200	0	0	0	0	0	0	0
11.5								0.200	0	0	0	0	0	0	0
12.5								0.500	0.100	0	0	0	0	0	0
13.5								0.900	0.300	0	0	0	0	0	0
14.5									0.500	0.100	0	0	0	0	0
15.5									1.000	0.200	0	0	0	0	0
16.5									1.000	0.800	0.200	0	0	0	0
17.5									1.000	0.900	0.100	0	0	0	0
18.5										0.800	0.300	0	0	0	0
19.5										1.000	0.900	0.300	0	0	0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)													
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	3, 0	3, 0	3, 0	3, 0	3, 0	3, 0	3, 0	2, 0	2, 0	2, 0	1, 0	1, 0	1, 0	0, 0	0, 0
1.5	9, 0	8, 0	8, 1	8, 1	8, 1	8, 1	8, 1	7, 1	6, 1	5, 0	4, 0	3, 0	2, 0	1, 0	0, 0
2.5		13, 1	9, 1	13, 1	10, 1	9, 0	9, 1	12, 1	10, 1	9, 1	7, 1	5, 0	3, 0	2, 0	1, 0
3.5			12, 1	13, 1	12, 1	12, 0	11, 1	10, 1	9, 1	12, 1	10, 1	7, 1	5, 1	3, 1	1, 0
4.5				15, 1	13, 1	13, 0	13, 1	12, 1	11, 1	11, 1	13, 1	9, 1	6, 1	4, 1	1, 0
5.5					16, 1	14, 1	14, 2	14, 1	12, 1	12, 1	11, 0	11, 1	8, 1	4, 1	2, 0
6.5					18, 4	18, 3	17, 2	15, 2	14, 1	13, 1	12, 1	11, 1	9, 1	5, 1	2, 0
7.5						26,13	19, 3	18, 4	16, 2	14, 2	14, 1	12, 1	10, 1	6, 1	2, 0
8.5						37,26	31,17	21, 6	17, 2	17, 2	15, 2	14, 1	12, 1	7, 1	3, 0
9.5							53,23	30,14	21, 3	21, 3	18, 3	16, 2	13, 1	7, 2	3, 0
10.5							71,14	51,13	27, 4	23, 4	20, 3	17, 3	16, 2	8, 2	3, 0
11.5								65, 8	36,10	28, 4	24, 3	21, 3	17, 2	9, 2	3, 1
12.5								71,15	48,12	30, 3	24, 4	24, 4	19, 2	10, 2	4, 1
13.5								83, 8	62,17	39, 8	31, 6	25, 5	20, 3	16, 3	4, 1
14.5									72,12	53,12	36, 7	29, 5	24, 3	18, 4	4, 1
15.5									83, 8	62,11	44,11	33, 6	27, 5	20, 4	5, 1
16.5									90, 0	77,13	51,15	36, 8	27, 2	23, 4	5, 1
17.5									90, 0	83, 9	53,13	39,11	30, 2	23, 3	5, 1
18.5										83,12	71,14	42,10	33, 4	26, 3	6, 1
19.5										87, 6	84,10	59,19	38, 9	28, 3	6, 1

****** Capsize probabilities and maximum roll for given conditions ******

Calm water ship speed : 10.00 knots (5.15 m/s)
Propeller RPM : 67.50
Heading : 45.00 degrees

Simulation duration for roll statistics : 1800.00 seconds
A blank cell means value not computed

Observed capsize probability for given conditions

	Wave Period Tp (s)													
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.5			0	0	0	0	0	0	0	0	0	0	0	0	0
3.5			0	0	0	0	0	0	0	0	0	0	0	0	0
4.5				0	0	0	0	0	0	0	0	0	0	0	0
5.5					0	0	0	0	0	0	0	0	0	0	0
6.5					0	0	0	0	0	0	0	0	0	0	0
7.5						0.100	0	0	0	0	0	0	0	0	0
8.5						0.500	0	0	0	0	0	0	0	0	0
9.5							0.700	0	0	0	0	0	0	0	0
10.5							0.600	0.200	0	0	0	0	0	0	0
11.5								0.500	0	0	0	0	0	0	0
12.5								0.900	0.100	0	0	0	0	0	0
13.5								0.900	0.600	0	0	0	0	0	0
14.5									0.700	0.100	0	0	0	0	0
15.5									1.000	0.600	0.100	0	0	0	0
16.5									1.000	0.900	0.400	0.100	0	0	0
17.5									1.000	0.900	0.700	0.100	0	0	0
18.5										1.000	0.500	0.100	0	0	0
19.5										1.000	0.800	0.400	0	0	0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)													
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	3, 0	3, 0	2, 0	3, 0	3, 0	3, 0	3, 0	3, 0	3, 0	2, 0	2, 0	2, 0	1, 0	1, 0	0, 0
1.5	10, 1	8, 1	7, 1	8, 1	9, 1	10, 1	9, 1	8, 1	8, 1	7, 1	6, 1	5, 0	4, 0	2, 0	1, 0
2.5			11, 1	13, 1	10, 1	11, 1	11, 1	10, 1	10, 1	12, 1	11, 1	9, 1	7, 1	4, 1	2, 1
3.5			12, 1	12, 1	12, 1	13, 1	13, 1	12, 1	12, 1	11, 1	11, 1	10, 1	9, 1	5, 1	2, 1
4.5				14, 1	15, 1	15, 1	15, 1	15, 1	14, 1	13, 1	13, 1	12, 1	12, 1	7, 1	3, 1
5.5					23,15	20, 2	17, 2	17, 1	16, 1	15, 1	14, 1	13, 1	12, 1	8, 1	3, 2
6.5					32,15	23, 6	21, 2	20, 2	19, 1	17, 1	16, 1	15, 1	13, 1	10, 1	4, 2
7.5						50,19	30, 8	23, 3	20, 2	19, 2	18, 2	16, 1	15, 2	11, 2	5, 2
8.5						66,17	44,15	28, 4	23, 2	21, 2	20, 2	18, 2	16, 2	13, 1	5, 3
9.5							71,12	36, 5	27, 5	24, 3	21, 2	20, 2	17, 2	14, 1	6, 3
10.5							74,10	55,14	31, 7	27, 4	24, 2	21, 2	19, 2	16, 1	6, 3
11.5								72,14	41, 7	32, 7	26, 2	24, 2	21, 3	18, 2	7, 3
12.5								80, 9	54,13	36, 8	29, 4	25, 3	23, 3	19, 2	8, 4
13.5								82, 9	72,16	40, 7	31, 4	28, 3	26, 2	21, 2	8, 4
14.5									77, 8	59,11	36, 7	30, 5	26, 3	21, 2	15, 2
15.5									84, 7	73,12	47,12	33, 8	28, 3	24, 2	16, 2
16.5									87, 6	79, 9	62,25	38,17	29, 3	24, 1	17, 2
17.5									90, 0	87, 7	74,21	48,18	31, 3	26, 2	18, 2
18.5										87, 7	77,14	52,17	31, 3	27, 2	20, 2
19.5										90, 0	82,12	65,20	34, 6	28, 2	21, 2

****** Capsize probabilities and maximum roll for given conditions ******

Calm water ship speed : 10.00 knots (5.15 m/s)
Propeller RPM : 67.50
Heading : 60.00 degrees

Simulation duration for roll statistics : 1800.00 seconds
A blank cell means value not computed

Observed capsize probability for given conditions

	Wave Period Tp (s)													
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.5		0			0	0	0	0	0	0	0	0	0	0	0
6.5		0			0.100	0	0	0	0	0	0	0	0	0	0
7.5						0.100	0	0	0	0	0	0	0	0	0
8.5						0.300	0.200	0	0	0	0	0	0	0	0
9.5							0.500	0	0	0	0	0	0	0	0
10.5							0.700	0	0	0	0	0	0	0	0
11.5								0.400	0	0	0	0	0	0	0
12.5								0.600	0.200	0	0	0	0	0	0
13.5								0.800	0.500	0	0	0	0	0	0
14.5									0.700	0.100	0	0	0	0	0
15.5									0.900	0.400	0.200	0	0	0	0
16.5									1.000	0.800	0.200	0	0	0	0
17.5									1.000	0.900	0.700	0	0	0	0
18.5										1.000	0.800	0.100	0	0	0
19.5										1.000	1.000	0.500	0	0	0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)													
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	6,15	1, 0	1, 0	2, 0	3, 0	3, 0	3, 0	3, 0	3, 0	3, 0	2, 0	2, 0	2, 0	1, 0	0, 0
1.5		3, 0	3, 0	6, 1	8, 1	9, 1	10, 1	9, 1	8, 1	8, 1	7, 1	6, 1	5, 0	4, 0	1, 0
2.5		5, 0	6, 1	10, 1	10, 1	11, 1	12, 1	11, 1	14, 1	13, 1	12, 1	10, 1	9, 1	6, 1	2, 1
3.5		7, 1	8, 1	11, 1	13, 1	14, 1	14, 1	14, 1	13, 1	13, 1	12, 1	11, 1	12, 1	8, 1	3, 1
4.5		9, 1	10, 1	16, 2	16, 2	17, 2	17, 1	16, 1	16, 1	15, 1	15, 1	13, 1	11, 1	11, 1	4, 1
5.5		11, 1			31,11	21, 2	19, 1	19, 2	18, 1	17, 1	17, 1	15, 1	13, 1	13, 1	5, 1
6.5		13, 1			44,18	34, 9	26, 5	22, 2	21, 1	20, 1	18, 1	17, 1	15, 1	13, 1	5, 2
7.5						54,17	35,11	26, 4	23, 2	22, 1	20, 1	19, 1	17, 1	14, 1	6, 2
8.5						62,15	52,17	32, 8	26, 4	24, 2	22, 1	21, 1	18, 1	16, 1	7, 2
9.5							68,20	42, 8	30, 5	26, 2	24, 1	22, 1	21, 1	18, 1	8, 2
10.5							78,10	51,12	36, 7	30, 4	26, 2	24, 2	22, 2	19, 2	9, 2
11.5								62,13	44, 9	34, 6	29, 2	27, 2	24, 2	21, 1	10, 3
12.5								75, 9	59,13	41, 8	32, 2	29, 2	25, 1	23, 2	11, 3
13.5								83,10	69,10	49,14	34, 4	30, 1	27, 2	23, 2	18, 2
14.5									76,10	56,12	39, 4	32, 2	28, 2	24, 2	19, 2
15.5									84, 9	71,16	50,13	33, 3	28, 2	26, 2	21, 2
16.5									87, 6	78,11	58,19	36, 3	30, 2	27, 2	22, 2
17.5									90, 1	87, 7	76,18	43, 7	32, 2	28, 2	23, 3
18.5										88, 5	79,16	50,17	33, 2	29, 2	24, 2
19.5										90, 1	88, 5	67,21	35, 3	30, 2	25, 2

****** Capsize probabilities and maximum roll for given conditions ******

Calm water ship speed : 10.00 knots (5.15 m/s)
Propeller RPM : 67.50
Heading : 75.00 degrees

Simulation duration for roll statistics : 1800.00 seconds
A blank cell means value not computed

Observed capsize probability for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.5		0	0		0	0	0	0	0	0	0	0	0	0	0
6.5		0	0		0	0	0	0	0	0	0	0	0	0	0
7.5		0				0.100	0	0	0	0	0	0	0	0	0
8.5		0				0.600	0.100	0	0	0	0	0	0	0	0
9.5		0					0.700	0	0	0	0	0	0	0	0
10.5		0					0.500	0.100	0	0	0	0	0	0	0
11.5		0						0.400	0.100	0	0	0	0	0	0
12.5								0.600	0.400	0.100	0	0	0	0	0
13.5								0.700	0.400	0.300	0.100	0	0	0	0
14.5									0.700	0.500	0.100	0	0	0	0
15.5									0.800	0.600	0.200	0	0	0	0
16.5									1.000	1.000	0.200	0	0	0	0
17.5									1.000	1.000	0.500	0.100	0	0	0
18.5										1.000	0.900	0.100	0	0	0
19.5										1.000	0.900	0.200	0	0	0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	1, 1	1, 0	1, 0	1, 0	2, 0	2, 0	3, 0	3, 0	3, 0	3, 0	2, 0	2, 0	2, 0	1, 0	1, 0
1.5	2, 4	2, 0	3, 0	4, 1	6, 0	7, 0	8, 1	8, 1	8, 0	8, 0	7, 1	6, 0	5, 0	4, 0	2, 0
2.5		3, 0	5, 0	7, 1	10, 1	12, 1	11, 1	14, 1	14, 1	13, 1	12, 1	11, 1	9, 1	7, 1	3, 0
3.5		4, 0	7, 0	10, 1	13, 1	14, 1	14, 1	14, 1	13, 1	13, 0	12, 1	11, 1	13, 1	10, 1	5, 1
4.5		5, 1	9, 1	24,11	17, 3	18, 1	17, 1	17, 1	16, 1	16, 0	15, 1	13, 1	12, 1	10, 1	6, 1
5.5		6, 1	11, 1		33,14	25, 6	22, 2	20, 1	19, 0	18, 1	17, 1	16, 1	14, 1	12, 1	8, 1
6.5		7, 1	13, 1		50,17	32, 8	25, 3	22, 1	22, 1	21, 1	19, 1	18, 1	16, 1	13, 1	9, 1
7.5		8, 1				47,18	36,11	27, 3	24, 1	23, 1	22, 1	20, 1	18, 1	15, 1	10, 1
8.5		9, 1				62,19	49,18	32, 4	27, 2	26, 2	25, 1	22, 1	20, 1	16, 1	12, 1
9.5		10, 1					70,19	45, 8	31, 2	29, 1	27, 2	24, 1	21, 1	18, 1	14, 1
10.5		11, 1					71,16	49,13	37, 5	31, 2	29, 2	26, 1	23, 1	20, 1	15, 1
11.5		12, 1						63,18	47,13	35, 7	31, 2	28, 2	25, 2	21, 1	16, 1
12.5								80,11	61,15	43,17	32, 2	29, 2	26, 2	22, 1	17, 1
13.5								78,13	67, 9	58,22	40,18	31, 2	28, 2	24, 1	19, 1
14.5									77,11	67,20	45,17	32, 2	29, 2	25, 1	20, 1
15.5									81,10	72,15	54,18	34, 2	30, 2	26, 1	21, 1
16.5									88, 6	85, 7	58,20	39,11	31, 2	27, 2	22, 2
17.5									90, 0	86, 7	66,23	46,17	32, 2	28, 2	23, 2
18.5										88, 5	84,11	49,18	34, 2	30, 2	24, 2
19.5										90, 0	88, 7	53,22	35, 2	30, 2	25, 1

****** Capsize probabilities and maximum roll for given conditions ******

Calm water ship speed : 10.00 knots (5.15 m/s)
Propeller RPM : 67.50
Heading : 90.00 degrees

Simulation duration for roll statistics : 1800.00 seconds
A blank cell means value not computed

Observed capsize probability for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.5	0	0	0	0		0.400	0	0	0	0	0	0	0	0	0
8.5	0	0	0			0.700	0.100	0	0	0	0	0	0	0	0
9.5	0	0	0				0.400	0	0	0	0	0	0	0	0
10.5	0	0	0				0.600	0.200	0	0	0	0	0	0	0
11.5	0	0	0					0.600	0	0	0	0	0	0	0
12.5		0						0.900	0	0	0	0	0	0	0
13.5								1.000	0.200	0	0	0	0	0	0
14.5									0.800	0.200	0	0	0	0	0
15.5									0.800	0.300	0	0	0	0	0
16.5									1.000	0.900	0.200	0	0	0	0
17.5									1.000	1.000	0.300	0	0	0	0
18.5										1.000	0.900	0	0	0	0
19.5										1.000	1.000	0.300	0	0	0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	1, 0	1, 0	1, 0	1, 0	1, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	1, 0	1, 0
1.5	2, 0	2, 0	2, 0	3, 0	4, 0	5, 0	6, 0	7, 0	7, 0	7, 0	6, 0	6, 0	5, 0	4, 0	3, 0
2.5	3, 0	3, 0	3, 0	4, 0	6, 0	9, 1	10, 1	11, 1	11, 1	11, 1	10, 1	10, 1	9, 1	7, 1	5, 0
3.5	4, 0	4, 0	4, 0	6, 0	9, 1	12, 1	11, 1	12, 1	11, 1	11, 1	11, 0	13, 1	12, 1	10, 1	8, 1
4.5	5, 1	5, 0	5, 0	8, 0	11, 1	14, 1	14, 1	14, 1	14, 1	13, 1	13, 0	12, 0	11, 1	10, 1	10, 1
5.5	6, 1	6, 1	7, 0	9, 0	13, 1	19, 2	18, 1	17, 1	16, 1	15, 1	15, 1	14, 0	13, 1	11, 1	12, 1
6.5	7, 1	7, 1	8, 0	11, 0	50,18	23, 4	22, 1	20, 1	18, 1	18, 1	17, 1	16, 1	15, 1	13, 1	11, 1
7.5	8, 1	8, 1	9, 1	13, 0		50,24	30, 9	23, 1	21, 1	20, 1	20, 1	18, 1	17, 1	15, 1	12, 1
8.5	9, 1	9, 1	10, 1			70,16	42,19	29, 5	25, 2	23, 2	22, 1	20, 1	18, 1	16, 1	14, 1
9.5	10, 1	10, 1	11, 1				55,20	34, 8	29, 3	27, 3	25, 2	22, 1	20, 1	18, 1	15, 1
10.5	11, 1	11, 1	13, 1				73,17	51,16	33, 5	30, 3	27, 2	25, 1	22, 1	19, 1	16, 1
11.5	13, 1	12, 1	14, 1					69,14	40, 9	33, 4	29, 2	27, 1	24, 2	21, 1	17, 1
12.5		13, 1						80,10	48, 8	36, 2	32, 2	29, 2	26, 2	22, 2	19, 1
13.5								86, 5	58,12	47,13	35, 3	31, 2	28, 2	24, 2	20, 2
14.5									80,12	58,15	38, 6	33, 2	30, 2	25, 2	21, 2
15.5									79,16	64,15	44,11	33, 2	31, 2	26, 2	22, 2
16.5									86, 5	80, 8	51,18	35, 2	32, 1	27, 2	23, 1
17.5									89, 3	88, 5	65,18	39, 8	32, 2	28, 2	24, 1
18.5										86, 7	80,14	40, 4	34, 2	30, 2	25, 1
19.5										89, 3	88, 5	57,21	34, 1	30, 2	26, 1

****** Capsize probabilities and maximum roll for given conditions ******

Calm water ship speed : 10.00 knots (5.15 m/s)
Propeller RPM : 67.50
Heading : 105.00 degrees

Simulation duration for roll statistics : 1800.00 seconds
A blank cell means value not computed

Observed capsize probability for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	5.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.5	0	0	0	0	0	0.100	0	0	0	0	0	0	0	0	0
8.5	0	0	0	0		0.300	0	0	0	0	0	0	0	0	0
9.5	0	0	0				0.200	0.100	0	0	0	0	0	0	0
10.5	0	0	0				0.900	0.100	0	0	0	0	0	0	0
11.5	0	0	0					0.500	0.100	0	0	0	0	0	0
12.5	0	0						0.800	0.200	0.100	0	0	0	0	0
13.5	0	0						1.000	0.300	0.200	0	0	0	0	0
14.5	0	0							0.600	0.200	0	0	0	0	0
15.5	0	0							0.900	0.500	0	0	0	0	0
16.5	0	0							1.000	0.500	0.100	0	0	0	0
17.5	0	0							0.900	0.900	0.300	0	0	0	0
18.5	0									1.000	0.600	0.100	0	0	0
19.5	0									0.900	0.700	0.200	0.100	0	0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0, 0	0, 0	1, 0	1, 0	1, 0	1, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	1, 0	1, 0
1.5	1, 0	1, 0	2, 0	2, 0	3, 0	4, 0	5, 0	6, 0	6, 0	6, 0	6, 1	5, 0	5, 0	4, 0	3, 0
2.5	1, 0	2, 0	3, 0	4, 0	5, 0	7, 0	9, 0	10, 0	10, 1	10, 1	10, 1	9, 1	8, 0	7, 0	5, 0
3.5	2, 0	3, 0	4, 0	5, 0	6, 0	9, 1	12, 1	14, 1	11, 0	11, 0	10, 1	12, 1	11, 1	9, 1	7, 0
4.5	2, 0	3, 0	5, 0	6, 0	8, 0	12, 1	13, 1	13, 1	14, 1	13, 0	13, 1	12, 1	11, 1	12, 1	9, 0
5.5	2, 0	4, 0	7, 0	8, 1	10, 0	17, 2	17, 1	16, 1	17, 1	16, 1	15, 1	14, 1	13, 1	11, 1	11, 1
6.5	3, 0	5, 0	8, 0	9, 1	12, 0	22, 4	19, 2	19, 1	20, 2	18, 1	17, 1	16, 1	14, 1	12, 1	13, 1
7.5	3, 0	6, 0	9, 0	11, 1	14, 1	33,16	22, 2	22, 1	22, 2	20, 1	19, 2	18, 1	16, 1	14, 1	12, 1
8.5	4, 0	6, 0	10, 1	12, 1		52,23	28, 5	25, 2	24, 3	23, 1	22, 2	20, 2	18, 1	15, 1	13, 1
9.5	4, 0	7, 1	11, 1				51,17	34,16	26, 2	25, 2	24, 2	22, 2	19, 1	17, 1	14, 1
10.5	5, 0	8, 1	13, 1				81, 8	49,17	32, 9	28, 3	26, 2	24, 2	21, 1	18, 1	15, 2
11.5	5, 0	9, 1	14, 1					56,22	40,19	33,10	29, 3	26, 2	24, 2	20, 1	16, 2
12.5	6, 0	9, 1						76,16	46,18	39,18	31, 3	28, 2	26, 2	22, 1	18, 2
13.5	6, 0	10, 1						85, 6	62,13	44,18	32, 2	30, 1	28, 2	23, 2	19, 2
14.5	7, 1	11, 1							70,19	50,19	35, 2	32, 2	29, 1	25, 2	20, 2
15.5	7, 1	12, 1							85, 7	66,15	38, 8	34, 2	30, 2	27, 2	21, 2
16.5	7, 1	12, 1							87, 4	70,14	45,14	34, 2	32, 2	28, 2	22, 2
17.5	8, 1	13, 1							87, 7	82,10	60,17	36, 1	33, 3	28, 2	23, 2
18.5	8, 1									88, 5	72,14	42,17	33, 2	29, 2	24, 2
19.5	9, 1									83,21	78,15	47,18	39,18	30, 2	25, 1

****** Capsize probabilities and maximum roll for given conditions ******

Calm water ship speed : 10.00 knots (5.15 m/s)
Propeller RPM : 67.50
Heading : 120.00 degrees

Simulation duration for roll statistics : 1800.00 seconds
A blank cell means value not computed

Observed capsize probability for given conditions

	Wave Period Tp (s)													
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.5	0	0	0	0			0	0	0	0	0	0	0	0	0
10.5	0	0	0	0			0.200	0	0	0	0	0	0	0	0
11.5	0	0	0	0				0.200	0.100	0.100	0	0	0	0	0
12.5	0	0	0					0.300	0.100	0.100	0	0	0	0	0
13.5	0	0	0					0.500	0.200	0	0	0	0	0	0
14.5	0	0	0						0.100	0.200	0	0	0	0	0
15.5	0	0	0						0.700	0.200	0.100	0	0	0	0
16.5	0	0							0.900	0.500	0.100	0	0	0	0
17.5	0	0							0.800	0.900	0.200	0	0	0	0
18.5	0	0								1.000	0.400	0.200	0	0	0
19.5	0	0								0.900	0.600	0.200	0	0	0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)													
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0, 0	0, 0	0, 0	1, 0	1, 0	1, 0	1, 0	2, 0	2, 0	2, 0	2, 0	2, 0	1, 0	1, 0	1, 0
1.5	0, 0	1, 0	1, 0	2, 0	2, 0	3, 0	4, 0	5, 0	5, 0	5, 0	5, 0	5, 0	4, 0	4, 0	3, 0
2.5	1, 0	1, 0	2, 0	3, 0	4, 0	5, 0	7, 0	9, 0	9, 1	9, 1	9, 0	8, 0	7, 1	6, 0	5, 0
3.5	1, 0	1, 0	3, 0	4, 0	5, 0	8, 0	10, 1	12, 0	13, 1	13, 1	12, 1	11, 1	10, 1	9, 1	7, 1
4.5	1, 0	2, 0	4, 0	5, 0	7, 0	10, 1	13, 1	12, 1	13, 1	12, 0	12, 1	11, 1	13, 1	12, 1	9, 1
5.5	2, 0	2, 0	5, 0	6, 0	8, 0	12, 1	15, 2	15, 1	15, 1	15, 0	14, 1	13, 1	12, 1	11, 1	11, 1
6.5	2, 0	2, 0	5, 0	7, 1	10, 1	17, 2	18, 2	17, 1	18, 2	18, 1	16, 1	15, 2	13, 1	12, 1	13, 1
7.5	2, 0	3, 0	6, 0	9, 1	11, 1	21, 2	20, 2	20, 1	20, 2	19, 2	18, 1	16, 2	15, 1	14, 1	11, 1
8.5	2, 0	3, 0	7, 0	10, 1	13, 1	30, 9	24, 4	23, 2	21, 1	21, 2	20, 2	18, 2	16, 1	15, 1	13, 1
9.5	3, 0	3, 0	8, 1	11, 1			31, 7	25, 2	23, 1	23, 2	22, 1	19, 1	18, 1	17, 1	14, 1
10.5	3, 0	4, 0	9, 1	12, 1			41,20	28, 8	30,14	24, 3	22, 1	21, 1	19, 1	18, 1	15, 1
11.5	3, 0	4, 0	10, 1	13, 1				46,24	36,20	32,19	23, 1	22, 1	21, 1	19, 1	16, 1
12.5	3, 0	4, 0	11, 1					50,24	38,18	34,20	26, 2	23, 1	22, 1	20, 1	17, 2
13.5	4, 0	5, 0	11, 1					68,21	46,18	34,12	27, 3	24, 2	23, 2	21, 1	18, 2
14.5	4, 0	5, 0	12, 1						46,17	45,22	31, 3	26, 3	24, 2	22, 2	19, 2
15.5	4, 0	6, 0	13, 1						76,18	51,21	38,14	28, 3	25, 3	23, 2	20, 1
16.5	5, 0	6, 1							84,13	68,20	42,17	30, 3	26, 3	25, 2	21, 2
17.5	5, 0	6, 1							81,15	84,12	53,19	34, 2	28, 2	26, 2	22, 2
18.5	5, 0	7, 1								86, 6	60,25	46,20	29, 2	27, 2	23, 2
19.5	5, 1	7, 1								87, 8	72,20	46,23	33, 4	28, 2	24, 2

****** Capsize probabilities and maximum roll for given conditions ******

Calm water ship speed : 10.00 knots (5.15 m/s)
Propeller RPM : 67.50
Heading : 135.00 degrees

Simulation duration for roll statistics : 1800.00 seconds
A blank cell means value not computed

Observed capsize probability for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.5	0	0	0	0	0		0	0	0	0	0	0	0	0	0
10.5	0	0	0	0	0		0	0	0	0	0	0	0	0	0
11.5	0	0	0	0	0			0	0	0	0	0	0	0	0
12.5	0	0	0	0	0			0	0	0	0	0	0	0	0
13.5	0	0	0	0				0	0	0	0	0	0	0	0
14.5	0	0	0	0					0	0	0	0	0	0	0
15.5	0	0	0	0					0.200	0.200	0	0	0	0	0
16.5	0	0	0						0.500	0.100	0	0	0	0	0
17.5	0	0	0						0.900	0.100	0	0	0	0	0
18.5	0	0	0							1.000	0.200	0	0	0	0
19.5	0	0	0							0.900	0.600	0.100	0	0	0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0, 0	0, 0	0, 0	0, 0	1, 0	1, 0	1, 0	1, 0	1, 0	2, 0	1, 0	1, 0	1, 0	1, 0	1, 0
1.5	0, 0	0, 0	1, 0	1, 0	2, 0	2, 0	3, 0	4, 0	4, 0	5, 0	4, 0	4, 0	4, 0	3, 0	3, 0
2.5	1, 0	1, 0	1, 0	2, 0	3, 0	4, 0	5, 0	7, 0	7, 0	8, 1	7, 0	7, 0	6, 0	5, 0	4, 0
3.5	1, 0	1, 0	2, 0	3, 0	4, 0	6, 1	7, 0	10, 0	10, 0	11, 1	10, 1	10, 1	9, 0	8, 0	6, 0
4.5	1, 0	1, 0	2, 0	4, 0	5, 0	7, 1	10, 1	12, 1	13, 1	11, 1	13, 1	13, 1	11, 0	10, 1	8, 0
5.5	1, 0	1, 0	3, 0	4, 1	6, 0	9, 1	12, 1	13, 1	14, 2	13, 1	12, 0	11, 1	13, 1	12, 1	10, 1
6.5	2, 0	2, 0	3, 0	5, 1	7, 0	10, 1	15, 1	16, 2	16, 1	15, 1	14, 1	13, 1	11, 1	10, 1	11, 1
7.5	2, 0	2, 0	4, 0	6, 1	8, 1	12, 1	19, 2	19, 2	18, 1	17, 1	16, 1	15, 1	13, 1	11, 1	13, 1
8.5	2, 0	2, 0	4, 0	7, 1	9, 1	24, 5	20, 2	21, 1	20, 1	18, 1	18, 1	16, 0	14, 1	13, 1	11, 1
9.5	2, 0	3, 0	5, 0	7, 1	10, 1		27, 3	25, 3	22, 1	21, 1	20, 1	17, 1	16, 1	14, 1	12, 1
10.5	3, 0	3, 0	5, 0	8, 1	11, 1		29, 5	30, 6	24, 1	23, 1	21, 1	19, 1	17, 1	15, 1	13, 1
11.5	3, 0	3, 0	5, 0	9, 1	12, 1			33,10	26, 2	26, 2	23, 2	21, 2	18, 1	16, 1	14, 1
12.5	3, 0	3, 0	6, 1	10, 1	13, 1			38, 6	28, 3	28, 4	24, 2	22, 2	19, 1	16, 1	14, 1
13.5	3, 0	4, 0	6, 1	11, 1				38, 5	34, 4	32, 5	26, 2	23, 2	20, 1	17, 1	15, 1
14.5	4, 0	4, 0	7, 1	11, 1					35, 5	32, 4	29, 3	26, 2	21, 1	18, 1	16, 1
15.5	4, 0	4, 0	7, 1	12, 1					54,18	47,23	32, 4	28, 4	23, 2	19, 2	16, 1
16.5	4, 0	4, 0	8, 1						67,15	47,16	33, 4	32, 4	25, 3	20, 3	17, 1
17.5	4, 0	5, 0	8, 1						81, 8	57,15	37, 4	39,12	28, 4	21, 3	18, 1
18.5	5, 0	5, 0	9, 1							84, 8	49,18	35, 8	30, 3	23, 4	19, 1
19.5	5, 1	5, 0	9, 1							84, 9	74,22	43,18	31, 4	25, 5	20, 2

****** Capsize probabilities and maximum roll for given conditions ******

Calm water ship speed : 10.00 knots (5.15 m/s)
Propeller RPM : 67.50
Heading : 150.00 degrees

Simulation duration for roll statistics : 1800.00 seconds
A blank cell means value not computed

Observed capsize probability for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	5.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.5	0	0	0	0	0	0		0	0	0	0	0	0	0	0
12.5	0	0	0	0	0	0		0	0	0	0	0	0	0	0
13.5	0	0	0	0	0			0	0	0	0	0	0	0	0
14.5	0	0	0	0	0				0	0	0	0	0	0	0
15.5	0	0	0	0	0				0.200	0	0	0	0	0	0
16.5	0	0	0	0	0				0.300	0	0	0	0	0	0
17.5	0	0	0	0	0				0.600	0.200	0	0	0	0	0
18.5	0	0	0	0	0					0.500	0	0	0	0	0
19.5	0	0	0	0						1.000	0.100	0	0	0	0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0, 0	0, 0	0, 0	0, 0	0, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0
1.5	0, 0	0, 0	1, 0	1, 0	1, 0	2, 0	2, 0	3, 0	3, 0	3, 0	3, 0	3, 0	3, 0	2, 0	2, 0
2.5	1, 0	1, 0	1, 0	1, 0	2, 0	3, 0	4, 0	5, 0	5, 0	6, 0	5, 0	5, 0	4, 0	4, 0	3, 0
3.5	1, 0	1, 0	1, 0	2, 0	2, 0	4, 0	5, 0	7, 0	7, 0	8, 0	8, 1	7, 0	6, 0	6, 0	4, 0
4.5	1, 0	1, 0	2, 0	2, 0	3, 0	5, 0	7, 1	9, 0	10, 0	10, 0	10, 1	9, 0	8, 0	7, 1	5, 0
5.5	1, 0	1, 0	2, 0	3, 0	4, 0	6, 1	8, 1	11, 1	12, 1	12, 0	12, 1	12, 0	10, 0	9, 1	7, 1
6.5	1, 0	2, 0	2, 0	3, 0	5, 0	7, 1	10, 1	13, 1	12, 1	12, 1	12, 2	14, 1	12, 0	10, 1	8, 1
7.5	2, 0	2, 0	3, 0	4, 0	5, 0	8, 1	11, 1	15, 2	14, 1	14, 1	13, 1	12, 1	13, 0	12, 1	9, 1
8.5	2, 0	2, 0	3, 0	4, 0	6, 0	9, 1	13, 1	17, 2	17, 2	15, 1	14, 1	13, 1	11, 1	10, 1	10, 1
9.5	2, 0	2, 0	3, 0	5, 0	7, 1	10, 1	19, 2	20, 3	20, 2	18, 2	17, 1	15, 1	13, 1	11, 1	11, 1
10.5	2, 0	3, 0	4, 0	5, 0	7, 1	11, 1	24, 4	22, 3	21, 1	21, 2	20, 3	17, 2	14, 1	12, 1	13, 1
11.5	3, 0	3, 0	4, 0	6, 0	8, 1	12, 1		27, 5	24, 2	23, 3	21, 3	18, 1	16, 1	13, 1	10, 1
12.5	3, 0	3, 0	4, 0	6, 0	9, 1	13, 1		30, 4	27, 4	25, 2	23, 2	19, 1	17, 1	13, 1	11, 1
13.5	3, 0	3, 0	5, 1	7, 0	10, 1			33, 4	29, 3	27, 2	26, 3	21, 2	19, 2	14, 1	12, 1
14.5	3, 0	3, 0	5, 1	8, 1	10, 1				34,12	31, 3	28, 5	24, 4	20, 2	15, 1	12, 1
15.5	3, 0	4, 0	5, 1	8, 1	11, 1				47,20	32, 3	31, 4	24, 2	21, 3	16, 1	13, 1
16.5	4, 0	4, 0	6, 1	9, 1	12, 1				60,14	37, 6	34, 3	26, 2	23, 2	18, 2	14, 1
17.5	4, 0	4, 0	6, 1	9, 1	12, 1				75,14	53,22	35, 4	30, 3	24, 3	20, 2	14, 1
18.5	4, 0	4, 0	7, 1	10, 1	13, 1					73,14	43,12	31, 3	25, 2	21, 3	15, 1
19.5	4, 0	5, 0	7, 1	10, 1						83, 7	50,18	35, 4	28, 5	23, 3	16, 1

****** Capsize probabilities and maximum roll for given conditions ******

Calm water ship speed : 10.00 knots (5.15 m/s)
Propeller RPM : 67.50
Heading : 165.00 degrees

Simulation duration for roll statistics : 1800.00 seconds
A blank cell means value not computed

Observed capsize probability for given conditions

	Wave Period Tp (s)													
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.5	0	0	0	0	0	0			0.100	0	0	0	0	0	0
15.5	0	0	0	0	0	0			0.100	0	0	0	0	0	0
16.5	0	0	0	0	0	0			0.100	0	0	0	0	0	0
17.5	0	0	0	0	0	0			0.900	0.100	0	0	0	0	0
18.5	0	0	0	0	0	0				0.300	0	0	0	0	0
19.5	0	0	0	0	0					0.700	0.200	0	0	0	0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)													
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	0, 0	0, 0
1.5	0, 0	0, 0	1, 0	1, 0	1, 0	1, 0	1, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	1, 0	0, 0
2.5	1, 0	1, 0	1, 0	1, 0	1, 0	2, 0	2, 0	3, 0	3, 0	3, 0	3, 0	3, 0	3, 0	2, 0	1, 0
3.5	1, 0	1, 0	1, 0	2, 0	2, 0	2, 0	3, 0	4, 0	4, 0	4, 0	4, 0	4, 0	4, 0	3, 1	1, 0
4.5	1, 0	1, 0	2, 0	2, 0	2, 0	3, 0	4, 0	5, 0	5, 0	5, 0	6, 0	5, 0	5, 0	3, 1	1, 0
5.5	1, 0	1, 0	2, 0	3, 0	3, 0	4, 0	5, 0	6, 0	7, 0	7, 0	7, 0	7, 0	6, 0	4, 1	1, 0
6.5	2, 0	2, 0	2, 0	3, 0	3, 0	5, 0	6, 0	7, 0	8, 0	8, 1	8, 0	8, 0	7, 1	5, 1	2, 0
7.5	2, 0	2, 0	3, 0	3, 0	4, 0	5, 0	7, 0	8, 0	9, 1	9, 1	9, 1	9, 0	8, 1	6, 1	2, 0
8.5	2, 0	2, 0	3, 0	4, 0	5, 0	6, 1	8, 1	9, 1	10, 1	10, 1	11, 1	10, 0	9, 1	7, 1	2, 1
9.5	2, 0	2, 0	3, 0	4, 0	5, 0	7, 1	9, 1	11, 1	12, 1	12, 1	12, 1	11, 1	10, 1	7, 2	2, 1
10.5	2, 0	2, 0	4, 0	5, 0	6, 1	7, 1	10, 1	12, 1	13, 1	13, 1	12, 1	12, 1	11, 1	8, 2	3, 1
11.5	3, 0	3, 0	4, 0	5, 1	6, 1	8, 1	10, 1	13, 1	17, 1	16, 2	14, 2	14, 1	12, 1	9, 2	3, 1
12.5	3, 0	3, 0	4, 1	6, 1	7, 1	9, 1	11, 1	20, 4	21, 3	17, 2	16, 2	15, 3	12, 1	10, 2	3, 1
13.5	3, 0	3, 0	5, 1	6, 1	7, 1	10, 1	12, 1	24, 4	24, 3	21, 3	19, 5	16, 3	14, 2	10, 2	3, 1
14.5	3, 0	3, 0	5, 1	7, 1	8, 1	10, 1			32,16	25, 3	21, 3	17, 2	16, 3	11, 2	4, 1
15.5	4, 0	4, 0	5, 1	7, 1	8, 1	11, 1			41,19	30, 4	25, 5	20, 3	17, 3	12, 2	4, 1
16.5	4, 0	4, 0	6, 1	8, 1	9, 1	12, 1			45,18	36,12	27, 2	22, 4	19, 4	12, 1	4, 1
17.5	4, 0	4, 0	6, 1	8, 1	9, 1	12, 1			83, 9	47,16	33, 4	25, 6	21, 4	13, 2	5, 1
18.5	4, 0	4, 0	6, 1	8, 1	10, 1	13, 1				60,22	35, 5	29, 5	22, 4	14, 2	5, 1
19.5	5, 0	5, 0	7, 1	9, 1	10, 1					74,20	47,20	28, 3	24, 4	15, 2	5, 1

****** Capsize probabilities and maximum roll for given conditions ******

Calm water ship speed : 10.00 knots (5.15 m/s)
Propeller RPM : 67.50
Heading : 176.25 degrees

Simulation duration for roll statistics : 1800.00 seconds
A blank cell means value not computed

Observed capsize probability for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0
1.5	0, 0	0, 0	0, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	0, 0	0, 0	0, 0	0, 0	0, 0
2.5	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0
3.5	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0	1, 0
4.5	1, 0	1, 0	1, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	1, 0	1, 0	1, 0	1, 0	1, 0
5.5	1, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	2, 0	1, 0	1, 0	2, 0	2, 0
6.5	2, 0	2, 0	2, 0	2, 0	3, 0	3, 0	3, 0	2, 0	2, 1	2, 0	2, 1	2, 1	2, 0	2, 0	2, 0
7.5	2, 0	2, 0	2, 0	3, 0	3, 0	3, 0	3, 0	3, 0	3, 1	3, 1	2, 1	2, 1	2, 1	2, 0	2, 0
8.5	2, 0	2, 0	3, 0	3, 0	3, 1	3, 0	3, 0	3, 0	3, 1	3, 1	2, 1	2, 1	2, 1	2, 0	2, 0
9.5	3, 0	3, 0	3, 0	3, 0	4, 1	4, 0	4, 0	4, 0	3, 1	3, 1	3, 1	2, 1	2, 1	3, 0	3, 0
10.5	3, 0	3, 0	3, 0	4, 0	4, 1	4, 0	4, 0	4, 0	4, 1	4, 1	3, 1	3, 1	3, 1	3, 1	3, 0
11.5	3, 0	3, 0	4, 0	4, 0	5, 1	5, 0	5, 0	4, 0	4, 1	4, 1	3, 1	3, 1	3, 1	3, 1	3, 0
12.5	3, 0	3, 0	4, 0	4, 1	5, 1	5, 0	5, 0	5, 0	5, 1	5, 1	4, 1	3, 1	3, 1	4, 1	4, 0
13.5	4, 0	4, 0	4, 0	5, 1	5, 1	5, 0	5, 0	5, 1	5, 1	5, 1	4, 1	3, 1	3, 1	4, 1	4, 0
14.5	4, 0	4, 0	5, 0	5, 1	6, 1	6, 0	6, 1	6, 1	5, 1	5, 1	4, 1	3, 1	4, 1	4, 1	4, 0
15.5	4, 0	4, 0	5, 0	5, 1	6, 1	6, 0	6, 1	6, 1	6, 1	6, 1	5, 1	4, 1	4, 1	4, 1	4, 1
16.5	4, 0	5, 0	5, 0	6, 1	7, 1	7, 0	7, 1	6, 1	6, 1	6, 1	5, 1	4, 1	4, 1	5, 1	5, 1
17.5	5, 0	5, 0	6, 0	6, 1	7, 1	7, 0	7, 1	7, 1	6, 2	6, 1	5, 2	4, 1	4, 1	5, 1	5, 1
18.5	5, 0	5, 0	6, 0	6, 1	7, 1	7, 1	8, 1	7, 1	7, 2	7, 1	5, 2	4, 2	5, 1	5, 1	5, 1
19.5	5, 0	5, 1	6, 0	7, 1	8, 1	8, 1	8, 1	7, 1	7, 2	7, 1	6, 2	5, 2	5, 1	6, 1	6, 1

Run successfully completed
03-Feb-1999 15:34:14
Elapsed time for motion simulations : 463.025 hours

C Input for Program Pcapsize2

C.1 Description of Pcapsize2 Input Records

Record (a), Eighty Character Title
TITLE (char*80)

TITLE Alphanumeric title (maximum of 80 characters) which is written on output.

Record (b), Pcapref Simulation Data File
PCAPREFFILE (char*50)

PCAPREFFILE Output data file produced by Pcapref with maximum roll angles from simulations.

Record (c), Wave Scattergram File
WSFILE (char*50)

WSFILE Name of wave scattergram file with joint distribution of significant wave height and peak wave period. Pcapsize2 reads wave scattergram files written using the Shipop2 format.

Record (d), Number of Ship Speeds
NSPEED (1 integer)

NSPEED Number of ship speeds (maximum 10).

Note: Record (d) must be followed by NSPEED records (d1).

Record (d1), Ship Speed and Probability
SPEEDKNOT(I), PSPEED(I) (2 reals)

SPEEDKNOT(I) Ship speed in calm water (knots).

PSPEED(I) Fraction of time that ship travels at speed SPEEDKNOT(I).

Record (e), Number of Ship Headings
NHEAD (1 integer)

NHEAD Number of ship headings (maximum 36).

Note: Record (e) must be followed by NHEAD records (e1).

Record (e1), Ship Headings
HEAD(I), PHEAD(I) (2 reals)

HEAD(I) Desired ship headings (180 degrees for head seas).

PHEAD(I) Fraction of time spent at heading PHEAD(I).

Record (f), Seaway Duration
DURSEAWAY (1 real)

DURSEAWAY Seaway duration (s). This variable is typically set to 3600 (one hour).

Record (g), Ship Life and Fraction at Sea
SHIPLIFE, PATSEA (2 reals)

SHIPLIFE Ship life (years). This variable can be set to one to obtain annual capsize statistics.

PATSEA Fraction of life spent at sea.

Record (h), Maximum Roll Angle Range for Fitting Gumbel Distributions
ROLLFITUPPER, RANGETRUNC, NFITTRUNCMIN, FITERRSIMWARN (4 reals)

ROLLFITUPPER Upper limit of range for fitting Gumbel distribution (degrees). This variable must be in the range 0-90 degrees, and should typically be set to 90 degrees.

RANGETRUNC Size of roll angle range for fitting Gumbel distributions. This value must be between 0 and 90 degrees. A value of 20 degrees is recommended.

NFITTRUNCMIN Minimum number of simulation roll angles for fitting Gumbel distributions. This value must be at least 2.

FITERRSIMWARN Threshold for error (degrees) between Gumbel fit and simulation value for maximum roll angle based on exceedence probability from simulations. This values must be between 0 and 90 degrees.

Record (i), Upper Limit on Output Mean Value for Maximum Roll Angle
ROLLMEANLIM (1 real)

ROLLMEANLIM Upper limit on output value of mean for fitted Gumbel distribution (degrees). This variable is typically set to 90 degrees, the maximum possible roll angle from Fredyn.

Record (j), Maximum Roll Angle Parameters for Output Tables
ROLLOUTINC, ROLLOUTUPPER (2 reals)

ROLLOUTINC Roll angle increment for output tables (degrees).

ROLLOUTUPPER Upper roll angle for output tables (degrees).

Record (k), Capsize Roll Angle
ROLLCAPSIZE

ROLLCAPSIZE Capsize roll angle used for generating capsize statistics (degrees).

C.2 Sample Input

```
CPF, 10 knots, 30 min simulations, 10 seeds      <----- Title
pcref30min.dat                                   <----- Pcapref data file
noratlstab.dat  <----- Wave scattergram file
1                    <----- Number of ship speeds
10.0 1.0    <----- Ship speed, probability
13  <----- Number of headings
3.75 0.041685
15 0.08333
30 0.08333
45 0.08333
60 0.08333
75 0.08333
90 0.08333
105 0.08333
120 0.08333
135 0.08333
150 0.08333
165 0.08333
176.25 0.041685 <----- Heading, probability
3600.0 <----- Seaway duration for probabilities
1.0 0.33 <----- Ship life (years), fraction at sea
90.0 20.0 3 5.0    <----- Gumbel fit parameters
90.0  <----- Limited on output mean roll angle
5.0 90.0  <----- Increment and maximum for output roll angles
70.0  <----- Capsize roll angle
```

D Sample Output for Pcapsize2

```
Output from program PCAPSIZE2
Capsize risk analysis in irregular seas from time domain simulation data
Defence Research Establishment Atlantic
Program Version 2.0 - 25 February 1999

PCAPSIZE2 Run Title:
CPF, 10 knots, 30 min simulations, 10 seeds
11:02:54 16-Mar-1999


**********************  ECHO OF USER INPUT  **********************

PCAPREF post-processing file     : pcref30min.dat
Wave scattergram file : noratlstab.dat

 1 ship speeds
Speed (kt)   P(Speed)
 10.00        1.000
             -------
              1.000

13 ship headings
Heading (deg)   P(Heading)
   3.75          0.042
  15.00          0.083
  30.00          0.083
  45.00          0.083
  60.00          0.083
  75.00          0.083
  90.00          0.083
 105.00          0.083
 120.00          0.083
 135.00          0.083
 150.00          0.083
 165.00          0.083
 176.25          0.042
             -------
              1.000

Seaway duration for capsize probabilities (seconds) :    3600.0
Ship life (years) :       1.00

Fraction of life at sea :     0.3300


Parameters for fitting distributions
   Upper limit (deg)                                 :      90.0
   Roll angle range for truncated fit (deg)          :      20.0
   Minimum number of points for truncated fit        :         3
   Threshold for printing warning of poor fit (deg) :       5.0

Limit on output mean roll angle
   Upper limit (deg) :      90.00

Roll angles for output probabilities
   Increment   (deg) :       5.00
   Upper value (deg) :      90.00

Capsize roll angle (deg) :      70.00
```

********** USER WAVE SCATTERGRAM FILE **********

File name : noratlstab.dat
Description : North Atlantic Annual Bales Data, Max Hs changed from 8.5 m to 6.5 m for Tp = 9.

Number of wave height intervals : 20
Wave height increment : 1.000 m
Input sum of scattergram entries : 130339.0

Number of peak wave periods : 15
Peak wave period values (s)
3.20 4.50 6.30 7.50 8.50 9.70 10.90 12.40 13.90 15.00 16.40 18.00 20.00 22.50 25.70

User wave scattergram entries

Hs (m)	Peak wave period (s)														
	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.0- 1.0	541	341	5488	5622	3892	4861	2667	2612	1180	1321	592	213	52	4	0
1.0- 2.0	0	289	3929	6631	5475	5361	3627	3428	1617	1707	945	569	164	10	0
2.0- 3.0	0	0	29	2150	5501	5695	3829	2968	1598	1267	780	421	124	3	0
3.0- 4.0	0	0	0	5	822	4582	3873	3393	1457	1098	623	350	97	6	0
4.0- 5.0	0	0	0	0	13	613	3115	3381	1293	1008	556	316	75	12	0
5.0- 6.0	0	0	0	0	0	22	631	3014	1263	993	467	308	48	5	0
6.0- 7.0	0	0	0	0	0	2	27	1336	1103	934	429	287	40	0	0
7.0- 8.0	0	0	0	0	0	0	0	229	722	778	347	230	28	0	6
8.0- 9.0	0	0	0	0	0	0	0	16	218	599	310	200	31	0	7
9.0-10.0	0	0	0	0	0	0	0	2	26	187	316	163	20	2	1
10.0-11.0	0	0	0	0	0	0	0	0	1	41	202	106	21	1	0
11.0-12.0	0	0	0	0	0	0	0	0	0	7	67	95	15	0	1
12.0-13.0	0	0	0	0	0	0	0	0	0	0	14	58	18	0	0
13.0-14.0	0	0	0	0	0	0	0	0	0	0	14	58	18	0	0
14.0-15.0	0	0	0	0	0	0	0	0	0	0	0	13	13	2	1
15.0-16.0	0	0	0	0	0	0	0	0	0	0	0	13	13	2	1
16.0-17.0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0
17.0-18.0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0
18.0-19.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
19.0-20.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Correction factor applied to wave scattergram : 0.999992

```
******** ECHO OF HEADER FROM PCAPREF DATA FILE *******

File name      : pcref30min.dat
Title          :
CPF, 30 minute simulations, 0.001 tolerance, data corrected at 60 deg, Hs = 0.5
Date and time : 11:52:45 16-Dec-19

FREDYN file names
Base FREDYN input file        : fredynbase.inp
FREDYN input file             : fredyn.inp
FREDYN main output file       : fredyn.out
FREDYN time series data file : fredyn.dat

 1 ship speeds
Speed (knots)  Propeller RPM guess
   10.00         67.50

13 ship headings
Heading (deg)
    3.75
   15.00
   30.00
   45.00
   60.00
   75.00
   90.00
  105.00
  120.00
  135.00
  150.00
  165.00
  176.25

20 significant wave heights
Hs (m)
    0.50
    1.50
    2.50
    3.50
    4.50
    5.50
    6.50
    7.50
    8.50
    9.50
   10.50
   11.50
   12.50
   13.50
   14.50
   15.50
   16.50
   17.50
   18.50
   19.50
```

```
15 peak wave periods
Tp (s)
    3.20
    4.50
    6.30
    7.50
    8.50
    9.70
   10.90
   12.40
   13.90
   15.00
   16.40
   18.00
   20.00
   22.50
   25.70


Seed numbers for random waves
  Number of seeds        :       10
  Minimum seed number    :     1001
  Seed number increment  :        2


Wind flag and description : NOWIND                - No wind
Wind speed (m/s) = AWIND*Hs**2 + BWIND*Hs + CWIND
   AWIND (/(ms)) :    0.0000
   BWIND (/s)    :    0.0000
   CWIND (m/s)   :    0.0000
   Mininum seed number   :        0
   Seed number increment :        0


Time parameters (seconds)
  Simulation sample time          :   1800.00
  Delay before sampling           :     20.00
  Force ramp time                 :     20.00

Linear roll response parameters
  Maximum roll angle for linear response (deg)  :     15.00
  Reference wave height for linear response (m) :      0.50

Maximum roll response parameters
  Capsize roll angle (deg)                      :     70.00

Limit on wave steepness
  Limit is based on significant wave height Hs and peak wave period TP
  Limit :     0.060 (height/length)

Old data flag OLDDATAFLAG : USEOLDDATA
Old data file : pcref30min.dat
```

****** Capsize probabilities and maximum roll for ship in a seaway ******

Calm water ship speed : 10.00 knots
Heading : 3.75 degrees
Seaway duration for probabilities : 3600.00 seconds
Capsize roll angle : 70.00 degrees
Statistical properties based on Gumbel fits. * to right of values indicates poor Gumbel fit
A blank cell means value not computed because no waves occur

Computed capsize probability for given conditions

	Wave Period Tp (s)													
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.5		0	0	0	0	0	0	0	0	0	0	0	0	0	
2.5			0	0	0	0	0	0	0	0	0	0	0	0	
3.5				0	0	0	0	0	0	0	0	0	0	0	
4.5					0	0	0	0	0	0	0	0	0	0	
5.5						0	0	0	0	0	0	0	0	0	
6.5						0	0	0	0	0	0	0	0		
7.5								0	0	0	0	0	0		0
8.5								0	0	0	0	0	0		0
9.5								0	0	0	0	0	0	0	0
10.5									0	0	0	0	0	0	
11.5										0	0	0	0		0
12.5											0	0	0		
13.5											0	0	0		
14.5												0	0	0	0
15.5												0	0	0	0
16.5													0	0	
17.5													0	0	
18.5															0
19.5															0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)													
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	1,0	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
1.5		2,0	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
2.5			1,0	1,0	1,0	1,0	0,0	0,0	0,0	0,0	0,0	1,0	1,0	1,0	
3.5				1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	
4.5					1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	
5.5						1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	2,0	
6.5						1,0	1,0	1,0	1,0	1,0	1,0	1,0	2,0		
7.5								1,0	1,0	1,0	1,0	2,0	2,0		2,0
8.5								1,0	1,0	2,0	2,0	2,0	2,0		3,0
9.5								1,0	1,0	2,0	2,0	2,0	2,0	3,1	3,0
10.5									2,0	2,0	2,0	2,0	3,0	3,1	
11.5										2,0	2,0	2,0	3,0		4,0
12.5											2,0	3,0	3,0		
13.5											2,1	3,0	3,1		
14.5												3,1	3,1	4,1	4,1
15.5												3,1	4,1	4,1	5,1
16.5													4,1	5,1	
17.5													4,1	5,1	
18.5															6,1
19.5															6,1

****** Capsize probabilities and maximum roll for ship in a seaway ******

Calm water ship speed : 10.00 knots
Heading : 15.00 degrees
Seaway duration for probabilities : 3600.00 seconds
Capsize roll angle : 70.00 degrees
Statistical properties based on Gumbel fits. * to right of values indicates poor Gumbel fit
A blank cell means value not computed because no waves occur

Computed capsize probability for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.5		0	0	0	0	0	0	0	0	0	0	0	0	0	
2.5			0	0	0	0	0	0	0	0	0	0	0	0	
3.5				0	0	0	0	0	0	0	0	0	0	0	
4.5					0	0	0	0	0	0	0	0	0	0	
5.5						0	0	0	0	0	0	0	0	0	
6.5						0	0	0	0	0	0	0	0		
7.5								0	0	0	0	0	0		0
8.5								0	0	0	0	0	0		0
9.5								3E-7	4E-8	0	0	0	0	0	0
10.5									2E-5	2E-6*	0	0	0	0	
11.5										0.052	0	0	0		0
12.5											9E-6	0	0		
13.5											5E-5	0	0		
14.5												0	0	0	0
15.5												0	0	0	0
16.5													0	0	
17.5													0	0	
18.5															0
19.5															0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	3,0	2,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,0	0,0	0,0	
1.5		5,0	4,0	4,0	4,0	4,0	4,1	3,0	3,0	2,0	2,0	1,0	1,0	0,0	
2.5			7,1	7,1	7,1	7,1	6,1	5,1	4,1	4,1	3,0	2,0	1,0	1,0	
3.5				10,1	10,1	9,1	9,1	7,1	6,1	5,1	4,0	3,0	2,1	1,0	
4.5					12,1	12,1	11,2	9,1	8,1	7,1	5,1	4,1	2,1	1,0	
5.5						14,2	14,2	12,2	10,1	8,1	6,1	4,1	3,1	1,0	
6.5						14,2	13,1	11,1	11,2	10,1	7,1	5,1	4,1		
7.5								12,1	13,2	11,2	8,1	6,1	4,1		2,0
8.5								14,2	13,1	13,2	10,1	7,1	5,2		2,0
9.5								19,4	16,4	14,2	11,1	7,1	5,2	2,1	2,0
10.5									21,6	17,5*	12,1	8,1	6,2	3,1	
11.5										17,29	13,1	9,1	6,2		3,0
12.5											20,6	10,1	7,2		
13.5											25,6	11,2	7,3		
14.5												11,2	8,3	4,1	4,1
15.5												12,2	8,3	4,1	4,1
16.5													9,3	4,1	
17.5													10,3	4,1	
18.5															5,1
19.5															5,1

Conditions with poor Gumbel fits exceeding allowable fit error (deg) : 5.0

Hs (m)	Tp (s)	Maximum fit error for simulations (deg)
10.5	15.0	5.3

****** Capsize probabilities and maximum roll for ship in a seaway ******

Calm water ship speed : 10.00 knots
Heading : 30.00 degrees
Seaway duration for probabilities : 3600.00 seconds
Capsize roll angle : 70.00 degrees
Statistical properties based on Gumbel fits. * to right of values indicates poor Gumbel fit
A blank cell means value not computed because no waves occur

Computed capsize probability for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.5		0	0	0	0	0	0	0	0	0	0	0	0	0	
2.5			0	0	0	0	0	0	0	0	0	0	0	0	
3.5				0	0	0	0	0	0	0	0	0	0	0	
4.5					0	0	0	0	0	0	0	0	0	0	
5.5						0	0	0	0	0	0	0	0	0	
6.5						2E-7	0	0	0	0	0	0	0		
7.5								4E-7	0	0	0	0	0		0
8.5								1E-4	0	0	0	0	0		0
9.5								0.127*	6E-6	4E-7	3E-8	0	0	0	0
10.5									4E-5	7E-6	9E-8	3E-9	0	0	
11.5										1E-5	1E-6	6E-8	0		0
12.5											4E-6	2E-5	0		
13.5											0.002	5E-5	6E-9		
14.5												2E-4	1E-6	5E-7	0
15.5												0.001*	2E-4	8E-7	0
16.5													3E-8	5E-6	
17.5													3E-9	5E-7	
18.5															0
19.5															0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	3,0	3,0	3,0	3,0	3,0	3,0	3,0	2,0	2,0	2,0	1,0	1,0	1,0	0,0	
1.5		8,1	8,1	8,1	9,1	9,1	8,1	7,1	6,1	5,0	4,0	3,0	2,0	1,0	
2.5			10,1	14,1	10,1	9,0	10,1	12,1	11,1	9,1	7,1	5,1	4,1	2,0	
3.5				13,1	12,1	12,1	12,1	11,1	10,1	13,1	10,1	8,1	5,1	3,1	
4.5					14,1	14,0	13,1	13,1	12,1	11,1	13,1	10,1	7,1	4,1	
5.5						15,1	15,2	15,1	13,1	12,1	11,1	12,1	8,1	5,1	
6.5						21,4	18,2	17,2	15,2	14,1	12,1	12,1	10,1		
7.5								21,4	17,2	15,2	15,1	13,1	11,2		3,0
8.5								25,7	19,3	18,3	16,2	15,2	13,2		3,0
9.5								36,31*	23,4	23,4	20,4	17,3	14,2	8,2	3,1
10.5									30,5	26,5	22,4	19,3	17,2	9,2	
11.5										31,5	26,4	23,4	19,3		4,1
12.5											27,5	27,6	21,3		
13.5											36,7	28,6	22,3		
14.5												33,6	27,4	21,5	5,1
15.5												37,7*	31,6	22,5	5,1
16.5													29,3	25,5	
17.5													32,3	26,4	
18.5															6,1
19.5															7,1

Conditions with poor Gumbel fits exceeding allowable fit error (deg) : 5.0

Hs (m)	Tp (s)	Maximum fit error for simulations (deg)
9.5	12.4	8.5
15.5	18.0	5.1

****** Capsize probabilities and maximum roll for ship in a seaway ******

Calm water ship speed : 10.00 knots
Heading : 45.00 degrees
Seaway duration for probabilities : 3600.00 seconds
Capsize roll angle : 70.00 degrees
Statistical properties based on Gumbel fits. * to right of values indicates poor Gumbel fit
A blank cell means value not computed because no waves occur

Computed capsize probability for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.5		0	0	0	0	0	0	0	0	0	0	0	0	0	
2.5			0	0	0	0	0	0	0	0	0	0	0	0	
3.5				0	0	0	0	0	0	0	0	0	0	0	
4.5					0	0	0	0	0	0	0	0	0	0	
5.5						0	0	0	0	0	0	0	0	0	
6.5						0.004	0	0	0	0	0	0	0		
7.5								3E-7	0	0	0	0	0		0
8.5								7E-5	0	0	0	0	0		0
9.5								0.001	1E-4	1E-7	0	0	0	0	0
10.5									0.005	2E-6	0	0	0	0	
11.5										0.011	3E-9	0	2E-9		5E-9
12.5											3E-5	1E-7	7E-9		
13.5											9E-5	5E-6	3E-9		
14.5												8E-5*	3E-8	1E-9	0
15.5												0.089	8E-7	0	0
16.5													7E-7	0	
17.5													5E-7	0	
18.5															0
19.5															0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	4,0	3,0	2,0	3,0	3,0	3,0	3,1	3,0	3,0	2,0	2,0	2,0	1,0	1,0	
1.5		9,1	7,1	8,1	10,1	10,1	10,2	9,1	8,1	7,1	7,1	6,1	4,0	2,0	
2.5			12,1	14,1	11,1	11,1	11,1	10,1	10,1	12,2	11,1	10,1	7,1	4,1	
3.5				12,1	13,1	14,1	14,1	13,1	13,1	12,1	11,1	10,1	10,1	6,1	
4.5					15,1	16,1	16,1	15,1	15,1	14,1	13,1	12,1	13,1	7,1	
5.5						21,2	19,2	18,2	17,2	16,1	15,2	14,1	12,1	9,1	
6.5						27,11	22,2	21,2	20,2	18,1	17,2	16,1	14,2		
7.5								25,4	21,2	20,2	19,2	18,2	16,2		6,3
8.5								32,5	24,2	23,2	21,2	19,2	17,2		7,3
9.5								39,6	31,6	26,4	23,2	21,3	19,3	15,1	8,3
10.5									37,9	30,4	25,2	23,2	21,3	17,2	
11.5										38,11	28,3	25,2	23,3		10,4
12.5											32,5	28,4	25,3		
13.5											34,5	31,4	27,3		
14.5												33,5*	28,3	23,3	16,3
15.5												32,27	30,4	25,3	17,3
16.5													31,4	26,2	
17.5													33,3	27,2	
18.5															21,2
19.5															23,2

Conditions with poor Gumbel fits exceeding allowable fit error (deg) : 5.0

Hs (m)	Tp (s)	Maximum fit error for simulations (deg)
14.5	18.0	5.6

****** Capsize probabilities and maximum roll for ship in a seaway ******

Calm water ship speed : 10.00 knots
Heading : 60.00 degrees
Seaway duration for probabilities : 3600.00 seconds
Capsize roll angle : 70.00 degrees
Statistical properties based on Gumbel fits. * to right of values indicates poor Gumbel fit
A blank cell means value not computed because no waves occur

Computed capsize probability for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.5		0	0	0	0	0	0	0	0	0	0	0	0	0	
2.5			0	0	0	0	0	0	0	0	0	0	0	0	
3.5				0	0	0	0	0	0	0	0	0	0	0	
4.5					0	0	0	0	0	0	0	0	0	0	
5.5						0	0	0	0	0	0	0	0	0	
6.5						0.018	3E-4	0	0	0	0	0	0		
7.5								2E-5	0	0	0	0	0		0
8.5								0.016	4E-6	0	0	0	0		0
9.5								0.028	1E-4	1E-8	0	0	0	0	0
10.5									0.020	3E-5	0	0	0	0	
11.5										0.002	8E-9	3E-9	0		0
12.5											5E-8	0	0		
13.5											3E-5	0	0		
14.5												4E-9	0	0	0
15.5												3E-6	0	0	0
16.5													0	0	
17.5													6E-8	1E-9	
18.5															6E-9
19.5															1E-9

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	2,0	1,0	1,0	2,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	2,0	2,0	1,0	
1.5		3,0	4,0	6,1	9,1	10,1	10,1	10,1	9,1	8,1	8,1	7,1	5,1	4,0	
2.5			6,1	11,1	11,1	12,1	12,1	12,1	14,1	14,1	13,1	11,1	9,1	6,1	
3.5				12,1	14,1	15,1	15,1	14,1	14,1	14,1	13,1	12,1	13,1	9,1	
4.5					17,2	18,2	18,1	17,1	17,1	16,1	16,2	14,2	12,1	11,1	
5.5						22,3	20,2	20,2	19,1	18,1	18,2	16,1	14,1	14,1	
6.5						41,11	30,7	23,2	22,2	21,2	19,1	18,1	16,1		
7.5								29,5	24,2	23,2	21,1	20,1	18,1		8,2
8.5								38,12	29,4	25,2	23,1	21,1	20,2		9,2
9.5								49,9	33,6	28,3	25,2	23,1	22,2	19,2	10,3
10.5									41,11	33,5	28,2	26,3	24,2	20,2	
11.5										38,7	30,3	28,3	25,2		12,3
12.5											33,3	30,2	26,2		
13.5											37,4	31,2	28,2		
14.5												33,3	29,3	26,2	21,2
15.5												35,4	30,2	27,2	22,3
16.5													31,2	28,2	
17.5													33,3	29,3	
18.5															26,3
19.5															27,3

****** Capsize probabilities and maximum roll for ship in a seaway ******

Calm water ship speed : 10.00 knots
Heading : 75.00 degrees
Seaway duration for probabilities : 3600.00 seconds
Capsize roll angle : 70.00 degrees
Statistical properties based on Gumbel fits. * to right of values indicates poor Gumbel fit
A blank cell means value not computed because no waves occur

Computed capsize probability for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.5		0	0	0	0	0	0	0	0	0	0	0	0	0	
2.5			0	0	0	0	0	0	0	0	0	0	0	0	
3.5				0	0	0	0	0	0	0	0	0	0	0	
4.5					0	0	0	0	0	0	0	0	0	0	
5.5						3E-4	0	0	0	0	0	0	0	0	
6.5						0.015	2E-8	0	0	0	0	0	0		
7.5								1E-7	0	0	0	0	0		0
8.5								2E-4	0	0	0	0	0		0
9.5								0.029	3E-8	0	0	0	0	0	0
10.5									0.001	0	1E-9	0	0	0	
11.5										0.066	4E-9	0	0		0
12.5											3E-8	0	0		
13.5											3E-5	0	0		
14.5												8E-9	0	0	0
15.5												2E-7	0	0	0
16.5													0	0	
17.5													9E-9	1E-9	
18.5															0
19.5															0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	2,1	1,0	1,0	2,0	2,0	3,0	3,0	3,0	3,0	3,0	2,0	2,0	2,0	2,0	
1.5		2,0	3,0	5,1	6,1	8,1	9,1	9,1	8,1	8,0	7,1	7,0	6,0	5,1	
2.5			5,0	8,1	10,1	13,1	12,1	14,1	14,1	13,1	12,1	11,1	10,1	8,1	
3.5				11,2	13,1	15,1	15,1	14,1	14,1	13,1	13,1	11,1	13,1	11,1	
4.5					19,3	18,2	18,1	18,1	17,1	16,1	15,1	14,1	12,1	11,1	
5.5						29,7	24,3	20,1	19,1	19,1	17,1	16,1	15,1	12,1	
6.5						38,11	27,3	23,1	22,1	21,1	20,1	18,1	17,1		
7.5								29,3	25,1	24,2	23,1	21,1	19,1		11,2
8.5								36,5	28,2	27,2	26,1	23,1	21,2		13,2
9.5								51,8	33,3	30,2	28,2	25,1	22,2	19,1	14,1
10.5									40,6	32,2	30,3	27,2	24,2	20,1	
11.5										36,21	32,3	29,2	26,2		17,1
12.5											34,3	31,2	28,2		
13.5											37,4	32,2	29,2		
14.5												34,3	31,2	26,1	21,1
15.5												36,3	31,2	27,1	22,2
16.5													32,2	28,2	
17.5													34,3	30,3	
18.5															25,2
19.5															26,2

****** Capsize probabilities and maximum roll for ship in a seaway ******

Calm water ship speed : 10.00 knots
Heading : 90.00 degrees
Seaway duration for probabilities : 3600.00 seconds
Capsize roll angle : 70.00 degrees
Statistical properties based on Gumbel fits. * to right of values indicates poor Gumbel fit
A blank cell means value not computed because no waves occur

Computed capsize probability for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.5		0	0	0	0	0	0	0	0	0	0	0	0	0	
2.5			0	0	0	0	0	0	0	0	0	0	0	0	
3.5				0	0	0	0	0	0	0	0	0	0	0	
4.5					0	0	0	0	0	0	0	0	0	0	
5.5						0	0	0	0	0	0	0	0	0	
6.5						1E-5	0	0	0	0	0	0	0		
7.5								0	0	0	0	0	0		0
8.5								5E-5*	0	0	0	0	0		0
9.5								0.090	4E-8	3E-8	0	0	0	0	0
10.5									0.001	5E-6	2E-9	0	0	0	
11.5										3E-5	0	0	0		0
12.5											5E-8	0	0		
13.5											1E-5	0	0		
14.5												2E-8	3E-8	0	0
15.5												0	0	1E-9	0
16.5													0	1E-9	
17.5													0	0	
18.5															0
19.5															0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	1,0	1,0	1,0	1,0	1,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	
1.5		2,0	2,0	3,0	4,0	5,0	7,0	7,0	7,1	7,1	6,0	6,0	5,0	5,0	
2.5			3,0	4,0	6,1	9,1	11,1	12,1	12,1	11,1	11,1	10,1	9,1	8,1	
3.5				6,0	9,1	13,1	12,1	12,1	12,1	11,1	11,0	14,1	13,1	11,1	
4.5					12,1	15,1	15,1	15,1	14,1	14,1	13,1	13,1	12,1	10,1	
5.5						20,2	18,2	17,1	17,1	16,1	15,1	15,1	13,1	12,1	
6.5						27,5	23,2	20,1	19,1	19,1	18,1	17,1	15,1		
7.5								24,1	22,1	21,2	20,1	19,1	17,1		13,1
8.5								32,5*	26,2	25,2	23,2	21,1	19,1		14,1
9.5								33,27	30,3	29,3	26,2	23,2	21,1	19,1	16,1
10.5									37,6	33,4	29,3	26,2	23,2	20,2	
11.5										36,5	31,2	28,2	25,2		18,2
12.5											34,3	30,2	27,2		
13.5											37,4	33,2	29,2		
14.5												34,3	32,3	26,2	22,2
15.5												35,2	32,2	28,3	23,2
16.5													33,2	29,3	
17.5													34,2	30,2	
18.5															26,2
19.5															27,2

Conditions with poor Gumbel fits exceeding allowable fit error (deg) : 5.0

Hs (m)	Tp (s)	Maximum fit error for simulations (deg)
8.5	12.4	6.6

****** Capsize probabilities and maximum roll for ship in a seaway ******

Calm water ship speed : 10.00 knots
Heading : 105.00 degrees
Seaway duration for probabilities : 3600.00 seconds
Capsize roll angle : 70.00 degrees
Statistical properties based on Gumbel fits. * to right of values indicates poor Gumbel fit
A blank cell means value not computed because no waves occur

Computed capsize probability for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.5		0	0	0	0	0	0	0	0	0	0	0	0	0	
2.5			0	0	0	0	0	0	0	0	0	0	0	0	
3.5				0	0	0	0	0	0	0	0	0	0	0	
4.5					0	0	0	0	0	0	0	0	0	0	
5.5						0	0	0	0	0	0	0	0	0	
6.5						3E-6	0	0	0	0	0	0	0		
7.5								0	0	0	0	0	0		0
8.5								0	1E-8	0	0	0	0		0
9.5								0.195	4E-9	0	0	0	0	0	0
10.5									0.097*	1E-6	0	2E-9	0	0	
11.5										0.101	1E-7	2E-9	0		0
12.5											1E-6	0	0		
13.5											2E-7	0	0		
14.5												2E-9	0	0	0
15.5												3E-8	7E-8	0	0
16.5													1E-9	7E-9	
17.5													1E-7	1E-8	
18.5															0
19.5															0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0,0	0,0	1,0	1,0	1,0	1,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	1,0	
1.5		1,0	2,0	2,0	3,0	4,0	5,0	6,0	6,0	7,1	6,1	5,0	5,0	4,0	
2.5			3,0	4,0	5,0	7,0	9,1	10,1	11,1	11,1	10,1	9,1	8,0	7,1	
3.5				5,0	7,0	10,1	13,1	14,1	11,0	11,0	11,1	13,1	11,1	10,1	
4.5					8,0	13,1	14,1	14,1	14,1	14,1	13,1	12,1	11,1	13,1	
5.5						18,2	17,1	17,1	17,1	16,1	16,1	14,1	13,1	11,1	
6.5						25,5	20,2	20,1	21,2	19,1	18,2	16,1	15,1		
7.5								23,1	24,3	21,2	21,2	19,2	17,1		12,1
8.5								27,2	26,3	24,2	23,2	21,2	18,1		14,1
9.5								35,48	28,3	27,2	25,2	24,2	20,1	18,1	15,2
10.5									31,30*	31,4	27,2	26,3	22,2	19,1	
11.5										35,27	31,3	28,3	25,2		18,2
12.5											34,4	29,2	27,2		
13.5											34,3	31,2	29,2		
14.5												33,2	30,2	27,2	21,2
15.5												35,3	32,3	28,2	23,3
16.5													33,2	30,3	
17.5													35,3	30,3	
18.5															25,2
19.5															26,2

Conditions with poor Gumbel fits exceeding allowable fit error (deg) : 5.0

Hs (m)	Tp (s)	Maximum fit error for simulations (deg)
10.5	13.9	6.1

****** Capsize probabilities and maximum roll for ship in a seaway ******

Calm water ship speed : 10.00 knots
Heading : 120.00 degrees
Seaway duration for probabilities : 3600.00 seconds
Capsize roll angle : 70.00 degrees
Statistical properties based on Gumbel fits. * to right of values indicates poor Gumbel fit
A blank cell means value not computed because no waves occur

Computed capsize probability for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.5		0	0	0	0	0	0	0	0	0	0	0	0	0	
2.5			0	0	0	0	0	0	0	0	0	0	0	0	
3.5				0	0	0	0	0	0	0	0	0	0	0	
4.5					0	0	0	0	0	0	0	0	0	0	
5.5						0	0	0	0	0	0	0	0	0	
6.5						0	0	0	0	0	0	0	0		
7.5								0	0	0	0	0	0		0
8.5								0	0	0	0	0	0		0
9.5								1E-9	0	0	0	0	0	0	0
10.5									0.156*	1E-7	0	0	0	0	
11.5										0.208*	0	0	0		0
12.5											8E-9	0	0		
13.5											4E-8	0	0		
14.5												8E-8	0	0	0
15.5												2E-6	1E-7	0	0
16.5													3E-6	0	
17.5													9E-9	1E-9	
18.5															0
19.5															0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0,0	0,0	0,0	1,0	1,0	1,0	1,0	2,0	2,0	2,0	2,0	2,0	1,0	1,0	
1.5		1,0	1,0	2,0	2,0	3,0	4,0	5,0	6,0	6,0	6,0	5,0	4,0	4,0	
2.5			2,0	3,0	4,0	6,0	7,1	9,0	10,1	9,1	9,1	8,1	7,1	7,0	
3.5				4,0	5,0	8,1	10,1	12,1	13,1	13,1	13,1	12,1	10,1	9,1	
4.5					7,0	10,1	13,1	13,1	13,1	12,1	12,1	12,1	13,1	12,1	
5.5						13,1	16,2	16,2	16,2	15,1	15,1	14,2	12,1	11,1	
6.5						18,2	20,3	18,2	19,2	18,1	17,1	16,2	14,1		
7.5								21,2	21,2	20,2	19,2	18,2	15,1		12,1
8.5								24,3	22,1	22,2	21,2	19,2	17,1		14,1
9.5								27,3	24,1	24,2	23,2	20,1	19,1	17,1	15,2
10.5									26,47*	27,4	23,1	21,1	20,1	18,1	
11.5										25,66*	24,2	23,1	21,1		17,2
12.5											28,3	24,1	23,2		
13.5											29,3	25,2	24,2		
14.5												28,3	25,2	23,2	20,2
15.5												31,4	28,4	25,2	21,2
16.5													29,4	26,2	
17.5													30,3	27,3	
18.5															24,2
19.5															26,2

Conditions with poor Gumbel fits exceeding allowable fit error (deg) : 5.0

Hs (m)	Tp (s)	Maximum fit error for simulations (deg)
10.5	13.9	9.4
11.5	15.0	14.6

****** Capsize probabilities and maximum roll for ship in a seaway ******

Calm water ship speed : 10.00 knots
Heading : 135.00 degrees
Seaway duration for probabilities : 3600.00 seconds
Capsize roll angle : 70.00 degrees
Statistical properties based on Gumbel fits. * to right of values indicates poor Gumbel fit
A blank cell means value not computed because no waves occur

Computed capsize probability for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.5		0	0	0	0	0	0	0	0	0	0	0	0	0	
2.5			0	0	0	0	0	0	0	0	0	0	0	0	
3.5				0	0	0	0	0	0	0	0	0	0	0	
4.5					0	0	0	0	0	0	0	0	0	0	
5.5						0	0	0	0	0	0	0	0	0	
6.5						0	0	0	0	0	0	0	0		
7.5								0	0	0	0	0	0		0
8.5								0	0	0	0	0	0		0
9.5								1E-7	0	0	0	0	0	0	0
10.5									0	0	0	0	0	0	
11.5										1E-8	0	0	0		0
12.5											0	0	0		
13.5											0	0	0		
14.5												0	0	0	0
15.5												5E-6	0	0	0
16.5													2E-6	5E-9	
17.5													1E-5	2E-7	
18.5															0
19.5															0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0,0	0,0	0,0	0,0	1,0	1,0	1,0	1,0	2,0	2,0	2,0	1,0	1,0	1,0	
1.5		0,0	1,0	1,0	2,0	3,0	3,0	4,0	5,0	5,0	5,0	4,0	4,0	3,0	
2.5			1,0	2,0	3,0	4,0	6,0	7,0	8,0	8,1	8,1	7,1	6,0	6,0	
3.5				3,0	4,0	6,1	8,1	10,1	11,1	11,1	11,1	10,1	9,0	8,1	
4.5					5,0	8,1	10,1	13,1	14,1	11,1	14,1	13,1	11,1	10,1	
5.5						9,1	12,1	14,1	15,2	14,1	12,0	12,1	14,1	12,1	
6.5						11,1	16,2	17,2	17,2	16,1	14,1	14,1	12,1		
7.5								20,2	19,2	18,2	17,1	15,1	14,1		14,1
8.5								22,2	21,1	19,1	19,2	16,1	15,1		11,1
9.5								27,4	23,1	22,2	20,1	18,1	16,1	14,1	12,1
10.5									24,1	24,2	22,1	19,1	18,1	15,1	
11.5										28,3	24,2	22,2	19,1		14,1
12.5											25,2	23,2	20,1		
13.5											27,2	25,2	21,1		
14.5												28,2	22,2	19,2	16,1
15.5												31,4	25,2	21,2	17,1
16.5													28,4	22,3	
17.5													31,5	24,4	
18.5															20,2
19.5															22,2

****** Capsize probabilities and maximum roll for ship in a seaway ******

Calm water ship speed : 10.00 knots
Heading : 150.00 degrees
Seaway duration for probabilities : 3600.00 seconds
Capsize roll angle : 70.00 degrees
Statistical properties based on Gumbel fits. * to right of values indicates poor Gumbel fit
A blank cell means value not computed because no waves occur

Computed capsize probability for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.5		0	0	0	0	0	0	0	0	0	0	0	0	0	
2.5			0	0	0	0	0	0	0	0	0	0	0	0	
3.5				0	0	0	0	0	0	0	0	0	0	0	
4.5					0	0	0	0	0	0	0	0	0	0	
5.5						0	0	0	0	0	0	0	0	0	
6.5						0	0	0	0	0	0	0	0		
7.5								0	0	0	0	0	0		0
8.5								0	0	0	0	0	0		0
9.5								1E-7	0	0	0	0	0	0	0
10.5									0	0	5E-8	0	0	0	
11.5										4E-7	2E-9	0	0		0
12.5											0	0	0		
13.5											2E-8	1E-9	0		
14.5												3E-6	0	0	0
15.5												0	2E-9	0	0
16.5													3E-9	0	
17.5													5E-8	0	
18.5															0
19.5															0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0,0	0,0	0,0	0,0	0,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	
1.5		0,0	1,0	1,0	1,0	2,0	2,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	
2.5			1,0	1,0	2,0	3,0	4,0	5,0	6,0	6,0	6,1	5,0	5,0	4,0	
3.5				2,0	3,0	4,0	6,1	7,0	8,0	8,0	8,1	8,0	6,0	6,0	
4.5					3,0	5,0	7,1	9,1	10,1	10,0	10,1	10,0	8,0	8,1	
5.5						6,1	9,1	11,1	12,1	12,0	13,1	12,1	10,0	9,1	
6.5						7,1	10,1	13,1	12,1	12,1	13,2	14,1	12,1		
7.5								17,3	15,1	14,1	14,1	13,2	14,1		10,1
8.5								19,2	18,2	16,1	15,1	14,2	12,1		11,1
9.5								22,4	21,2	20,2	18,1	16,1	13,1	12,1	12,1
10.5									22,1	23,3	22,4	18,2	15,1	13,1	
11.5										26,4	22,3	19,2	16,1		11,1
12.5											24,3	20,2	18,1		
13.5											29,4	23,3	20,2		
14.5												26,5	22,3	16,1	13,1
15.5												26,3	23,3	17,1	14,1
16.5													25,3	19,2	
17.5													26,3	21,3	
18.5															16,1
19.5															17,1

****** Capsize probabilities and maximum roll for ship in a seaway ******

Calm water ship speed : 10.00 knots
Heading : 165.00 degrees
Seaway duration for probabilities : 3600.00 seconds
Capsize roll angle : 70.00 degrees
Statistical properties based on Gumbel fits. * to right of values indicates poor Gumbel fit
A blank cell means value not computed because no waves occur

Computed capsize probability for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.5		0	0	0	0	0	0	0	0	0	0	0	0	0	
2.5			0	0	0	0	0	0	0	0	0	0	0	0	
3.5				0	0	0	0	0	0	0	0	0	0	0	
4.5					0	0	0	0	0	0	0	0	0	0	
5.5						0	0	0	0	0	0	0	0	0	
6.5						0	0	0	0	0	0	0	0		
7.5								0	0	0	0	0	0		0
8.5								0	0	0	0	0	0		0
9.5								0	0	0	0	0	0	0	0
10.5									0	0	0	0	0	0	
11.5										0	0	0	0		0
12.5											0	2E-8	0		
13.5											2E-5	4E-8	0		
14.5												0	2E-9	0	0
15.5												1E-9	2E-9	0	0
16.5													5E-7	0	
17.5													4E-7	0	
18.5															0
19.5															0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)														
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0	1,0	1,0	1,0	1,0	1,0	0,0	
1.5		0,0	1,0	1,0	1,0	1,0	1,0	2,0	2,0	2,0	2,0	2,0	2,0	1,0	
2.5			1,0	1,0	1,0	2,0	2,0	3,0	3,0	3,0	3,0	3,0	3,0	2,0	
3.5				2,0	2,0	3,0	3,0	4,0	4,0	4,0	5,0	4,0	4,0	3,1	
4.5					3,0	3,0	4,0	5,0	6,0	6,0	6,0	6,0	5,1	4,1	
5.5						4,0	5,0	6,0	7,0	7,1	7,0	7,0	6,1	5,1	
6.5						5,1	6,1	8,1	8,1	8,1	8,1	8,0	7,1		
7.5								9,1	10,1	10,1	10,1	9,0	8,1		2,0
8.5								10,1	11,1	11,1	11,1	10,1	10,1		3,1
9.5								11,1	12,1	12,1	12,1	12,1	11,1	8,2	3,1
10.5									13,1	13,1	13,1	13,1	12,1	9,2	
11.5										18,3	16,2	14,1	13,1		3,1
12.5											17,3	17,4	13,2		
13.5											23,6	18,4	15,3		
14.5												18,3	18,3	13,2	4,1
15.5												22,3	19,3	14,3	5,1
16.5													21,4	13,2	
17.5													23,4	14,3	
18.5															6,1
19.5															6,1

****** Capsize probabilities and maximum roll for ship in a seaway ******

Calm water ship speed : 10.00 knots
Heading : 176.25 degrees
Seaway duration for probabilities : 3600.00 seconds
Capsize roll angle : 70.00 degrees
Statistical properties based on Gumbel fits. * to right of values indicates poor Gumbel fit
A blank cell means value not computed because no waves occur

Computed capsize probability for given conditions

	Wave Period Tp (s)													
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.5		0	0	0	0	0	0	0	0	0	0	0	0	0	
2.5			0	0	0	0	0	0	0	0	0	0	0	0	
3.5				0	0	0	0	0	0	0	0	0	0	0	
4.5					0	0	0	0	0	0	0	0	0	0	
5.5						0	0	0	0	0	0	0	0	0	
6.5						0	0	0	0	0	0	0	0		
7.5								0	0	0	0	0	0		0
8.5								0	0	0	0	0	0		0
9.5								0	0	0	0	0	0	0	0
10.5									0	0	0	0	0	0	
11.5										0	0	0	0		0
12.5											0	0	0		
13.5											0	0	0		
14.5												0	0	0	0
15.5												0	0	0	0
16.5													0	0	
17.5													0	0	
18.5															0
19.5															0

Expected maximum roll angle and standard deviation for given conditions

	Wave Period Tp (s)													
Hs (m)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
1.5		0,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,0	0,0	0,0	
2.5			1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	
3.5				1,0	2,0	1,0	2,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	
4.5					2,0	2,0	2,0	2,0	2,0	2,0	2,0	1,0	1,0	1,0	
5.5						2,0	2,0	2,0	2,1	2,0	2,1	2,1	2,0	2,0	
6.5						3,0	3,0	3,0	3,1	3,1	2,1	2,1	2,1		
7.5								3,0	3,1	3,1	3,1	2,1	2,1		2,0
8.5								4,0	4,1	4,1	3,1	3,1	3,1		3,0
9.5								4,0	4,1	4,1	3,1	3,1	3,1	3,1	3,0
10.5									4,1	4,1	4,1	3,1	3,1	3,1	
11.5										5,1	4,1	3,1	3,1		4,0
12.5											4,1	4,1	4,1		
13.5											5,1	4,1	4,1		
14.5												4,1	4,1	5,1	4,1
15.5												5,1	5,1	5,1	5,1
16.5													5,1	5,1	
17.5													5,2	6,1	
18.5															6,1
19.5															6,1

***** COMPUTED ROLL EXCEEDENCE PROBABILITIES *****

All ship speeds, headings, and wave conditions

Seaway duration : 3600.00 seconds
Duration in hours : 1.000
Ship life : 1.000 years
Fraction of life at sea : 0.330

Maximum roll (deg)	Exceedence probability Seaway	Ship life
5.0	0.503684	1.000000
10.0	0.288555	1.000000
15.0	0.099239	1.000000
20.0	0.030535	1.000000
25.0	0.007206	1.000000
30.0	0.001657	0.991727
35.0	0.000327	0.612029
40.0	0.000084	0.214832
45.0	0.000031	0.086150
50.0	0.000016	0.044010
55.0	9.467166E-6	0.026997
60.0	6.514846E-6	0.018657
65.0	4.837114E-6	0.013886
70.0	3.763069E-6	0.010819
75.0	3.015079E-6	0.008678
80.0	2.463416E-6	0.007096
85.0	2.040549E-6	0.005881
90.0	1.707782E-6	0.004925

***** FITTED DISTRIBUTIONS IN A SEAWAY *****

Computed and Gumbel fit to roll exceedence probability
in a seaway
All ship speeds, headings, and wave conditions

Seaway duration : 3600.00 seconds
Duration in hours : 1.000

Parameters for fitted Gumbel distribution
P(exceed) = 1 - exp(-exp(-alpha(roll - u)))
U : -0.5652 degrees
Alpha : 0.1863 /degrees
Mean : 2.5 degrees
Std dev : 6.9 degrees

Parameters for fitted Weibull distribution
P(exceed) = exp(-(roll/k)**beta)
Beta : 1.1507
K : 6.9627 degrees
Mean : 6.6 degrees
Std dev : 5.8 degrees

Parameters for fitted Type 2 max distribution
P(exceed) = 1 - exp(-(u/roll)**beta)
U : 8.3526 degrees
Beta : 5.8237 degrees
Mean : 9.5 degrees
Std dev : 2.5 degrees

Max roll (deg)	Exceedence probability Computed	Gumbel fit	Weibull fit	Type 2 fit
5.0	0.503684	0.298514	0.505021	1.000000
10.0	0.288555	0.130355	0.219421	0.295676
15.0	0.099239	0.053534	0.089055	0.032512
20.0	0.030535	0.021441	0.034474	0.006170
25.0	0.007206	0.008502	0.012863	0.001686
30.0	0.001657	0.003358	0.004656	0.000583
35.0	0.000327	0.001324	0.001642	0.000238
40.0	0.000084	0.000522	0.000566	0.000109
45.0	0.000031	0.000206	0.000191	0.000055
50.0	0.000016	0.000081	0.000063	0.000030
55.0	9.467166E-6	0.000032	0.000021	0.000017
60.0	6.514846E-6	0.000013	6.643817E-6	0.000010
65.0	4.837114E-6	4.951332E-6	2.103197E-6	6.464505E-6
70.0	3.763069E-6	1.950485E-6	0.656919E-6	4.198571E-6
75.0	3.015079E-6	0.768357E-6	0.202614E-6	2.809342E-6
80.0	2.463416E-6	0.302679E-6	0.061754E-6	1.929184E-6
85.0	2.040549E-6	0.119235E-6	0.018611E-6	1.355320E-6
90.0	1.707782E-6	0.046970E-6	0.005549E-6	0.971575E-6

**** Conditional Probabilities for Capsize ****

Capsize roll angle : 70.0 degrees
Capsize probability in a seaway : 0.000004

Conditional probabilities for ship speed

Ship speed (knots)	P(speed)	P(speed|C)	P(C|speed) Seaway	P(C|speed) Ship life
10.0	1.000000	1.000000	3.763069E-6	0.010819
	1.000000	1.000000		

Conditional probabilities for ship heading

Ship heading (deg)	P(head)	P(head|C)	P(C|head) Seaway	P(C|head) Ship life
3.8	0.041685	0.000000	0.000000	0.000000
15.0	0.083330	0.061639	2.783549E-6	0.008014
30.0	0.083330	0.051901	2.343764E-6	0.006752
45.0	0.083330	0.214271	9.676201E-6	0.027585
60.0	0.083330	0.069268	3.128052E-6	0.009002
75.0	0.083330	0.095471	4.311327E-6	0.012386
90.0	0.083330	0.030826	1.392052E-6	0.004016
105.0	0.083330	0.202752	9.156013E-6	0.026121
120.0	0.083330	0.273788	0.000012	0.035111
135.0	0.083330	0.000021	0.000949E-6	2.742049E-6
150.0	0.083330	0.000015	0.000687E-6	1.986364E-6
165.0	0.083330	0.000048	0.002172E-6	6.277435E-6
176.3	0.041685	0.000000	0.000000	0.000000
	1.000000	1.000000		

Conditional probabilities for significant wave height

Wave height (m)	P(Hs)	P(Hs|C)	P(C|Hs) seaway
0.5	0.225456	0.000000	0.000000
1.5	0.258954	0.000000	0.000000
2.5	0.186934	0.000000	0.000000
3.5	0.125104	0.000000	0.000000
4.5	0.079653	0.000751E-6	0.000000
5.5	0.051795	0.001015	0.073774E-6
6.5	0.031901	0.013993	1.650579E-6
7.5	0.017953	0.000972	0.203723E-6
8.5	0.010595	0.045566	0.000016
9.5	0.005501	0.160416	0.000110
10.5	0.002854	0.047867	0.000063
11.5	0.001419	0.523558	0.001388
12.5	0.000679	0.000334	1.852483E-6
13.5	0.000679	0.004651	0.000026
14.5	0.000215	0.000706	0.000012
15.5	0.000222	0.200910	0.003398
16.5	0.000038	4.432368E-6	0.434796E-6
17.5	0.000038	6.765725E-6	0.663688E-6
18.5	3.836121E-6	0.000533E-6	0.000523E-6
19.5	3.836121E-6	0.000058E-6	0.000057E-6
	1.000000	1.000000	

Conditional probabilities for nominal wave steepness

Steepness	P(Steep)	P(Steep|C)	P(C|Steep) seaway
0.0	0.047169	0.000000	0.000000
0.0	0.218306	0.000000	0.000000
0.0	0.180505	0.000810E-6	0.000000
0.0	0.232818	0.000351E-6	0.000000
0.0	0.136708	2.816455E-6	0.000078E-6
0.0	0.140460	0.001177	0.031531E-6
0.0	0.040866	0.208007	0.000019
0.0	0.000560	0.618892	0.004158
0.0	0.000376	0.159334	0.001595
0.0	0.002233	0.012588	0.000021
	1.000000	1.000000	

Conditional probabilities for peak wave period

Wave period (s)	P(Tp)	P(Tp|C)	P(C|Tp) seaway
3.2	0.004151	0.000000	0.000000
4.5	0.004834	0.000000	0.000000
6.3	0.072472	0.000000	0.000000
7.5	0.110542	0.000000	0.000000
8.5	0.120477	0.000761E-6	0.000000
9.7	0.162161	0.013603	0.315670E-6
10.9	0.136328	0.001405	0.038784E-6
12.4	0.156353	0.205729	4.951451E-6
13.9	0.080390	0.048711	2.280154E-6
15.0	0.076262	0.523917	0.000026
16.4	0.043433	0.004229	0.366424E-6
18.0	0.026078	0.202038	0.000029
20.0	0.005992	0.000365	0.229188E-6
22.5	0.000395	2.678230E-6	0.025507E-6
25.7	0.000134	0.001437E-6	0.000040E-6
	1.000000	1.000000	

Conditional probabilities for wave height and period combinations
Cell values are number of occurences per million
Blank cells indicate zero probability

Hs (m) | Wave Period Tp (s)	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0.5															
1.5															
2.5															
3.5															
4.5															
5.5						1015									
6.5						12588	1405								
7.5								972							
8.5								45424	142						
9.5								159334	1062	18	2				
10.5									47506	357	5				
11.5										523542	15	1			
12.5											89	245			
13.5											4118	533			
14.5												703	3		
15.5												200557	353		
16.5													2	2	
17.5													6		
18.5															
19.5															

Sum of conditional probabilities : 1.000000

E Wave Scattergram Files

E.1 Wave Scattergram File Format

Pcapsize2 can read wave scattergram files prepared by the program user. These files can be prepared from sources such as Bales [12].

When preparing a wave scattergram file, it is important to note that Pcapsize2 requires the file to have peak wave periods.

Each new input record or sub-record corresponds to a new file line. The format of the input file may be adjusted by inserting extra blanks between any numeric data, and by placing data from within any numeric record on separate lines; however, separate records cannot be combined on a single line.

Record (1), Description
DESCWAVE (char*80)

DESCWAVE File description (80 character max).

Record (2), Wave Height Parameters and Number of Observations
NHS, HSINC, SUMOBSIN (1 integer, 2 reals)

NHS Number of wave height ranges (Maximum 48).

HSINC Significant wave height increment (m). The increment is typically equal to 0.5 m or 1.0 m.

SUMOBSIN Sum of observations of wave scattergram. The sum is typically 1.0 for a normalized scattergram, or greater than 1,000 when scattergram entries are actual numbers of observations.

Record (3), Number of Peak Wave Periods
NTP (1 integer)

NTP Number of peak wave periods (Maximum 15).

Record (4), Peak Wave Periods
TP(J) (NTP reals)

TP(J) Array of nominal peak wave periods (s).

Next NHS Records, Lower Value of Significant Wave Height and Joint Observations of Significant Wave Height and Peak Wave Period
HSLOWER, OBSHSTP(I,J) (1 real, NTP reals)

HSLOWER Lower limit of significant wave height range for observations. This value must be set to (I-1)*HSINC, where I is the wave height range index.

OBSHSTP(I,J) Number of observations for wave height range I and nominal peak wave period TP(J).

Note: Pcapsize2 checks to ensure that the sum of all OBSHSTP(I,J) values is equal to SUMOBSIN from Record (2).

E.2 Sample Wave Scattergram File

North Atlantic Annual Bales Data, Max Hs changed from 8.5 to 6.5 m for Tp = 9.7
20 1 130339
15

	3.2	4.5	6.3	7.5	8.5	9.7	10.9	12.4	13.9	15.0	16.4	18.0	20.0	22.5	25.7
0	541	341	5488	5622	3892	4861	2667	2612	1180	1321	592	213	52	4	0
1	0	289	3929	6631	5475	5361	3627	3428	1617	1707	945	569	164	10	0
2	0	0	29	2150	5501	5695	3829	2968	1598	1267	780	421	124	3	0
3	0	0	0	5	822	4582	3873	3393	1457	1098	623	350	97	6	0
4	0	0	0	0	13	613	3115	3381	1293	1008	556	316	75	12	0
5	0	0	0	0	0	22	631	3014	1263	993	467	308	48	5	0
6	0	0	0	0	0	2	27	1336	1103	934	429	287	40	0	0
7	0	0	0	0	0	0	0	229	722	778	347	230	28	0	6
8	0	0	0	0	0	0	0	16	218	599	310	200	31	0	7
9	0	0	0	0	0	0	0	2	26	187	316	163	20	2	1
10	0	0	0	0	0	0	0	0	1	41	202	106	21	1	0
11	0	0	0	0	0	0	0	0	0	7	67	95	15	0	1
12	0	0	0	0	0	0	0	0	0	0	13.5	57.5	17.5	0	0
13	0	0	0	0	0	0	0	0	0	0	13.5	57.5	17.5	0	0
14	0	0	0	0	0	0	0	0	0	0	0	13	13	1.5	0.5
15	0	0	0	0	0	0	0	0	0	0	0	13	13	2	1
16	0	0	0	0	0	0	0	0	0	0	0	0	2.5	2.5	0
17	0	0	0	0	0	0	0	0	0	0	0	0	2.5	2.5	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5

References

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This report presents a method for predicting capsize risk of intact ships in a seaway. Ship speed and heading are assumed to be independent variables, and the joint distribution of significant wave height and peak wave period is obtained from a wave scattergram. For a given set of operating and environmental conditions, the time domain program Fredyn is used to determine the occurrence of ship capsize. For irregular seas, the dependence of capsize on wave process realization is modelled by fitting a Gumbel distribution to maximum absolute roll angles obtained from several different wave phase seed numbers. Ten simulations of 30 minute duration can adequately provide the distribution of maximum hourly roll angle for a given seaway and ship operating condition. Sample computations for a Canadian Patrol Frigate suggest that the method gives realistic estimates of annual capsize risk. The current implementation conservatively assumes that ship speed and headings are independent of wave conditions. Future work will examine ship operational profiles to include the influence of capsize avoidance action.

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